Spangenberg's
Steam and Electrical Engineering

—— IN ——

QUESTIONS AND ANSWERS

A COMPLETE REFERENCE BOOK FOR

Engineers, Electricians, Firemen, Linemen, Wire-men, Steam Fitters, Owners of Steam, Electric and Refrigerating Plants

—— TREATING ON ——

Stationary and Locomotive Engineering, Electricity, Compressed Air, Mechanical Refrigeration, Gas and Gasoline Engines, Hydraulic Elevators, Repair Work, Etc.

—— BY ——

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Former Instructor Practical Electrical Engineering,
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—— AND ——

E. W. PRATT, Master Mechanic.

Illustrated by Six Hundred and Forty-eight Engravings,
Especially made for this Book.

GEO. A. ZELLER, PUBLISHER,
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1904

ERRATA.

ELECTRICAL DIVISION.

Page.	Line.	
364	30	After "pressure." insert "than a 1" pipe under same pressure.
365	9	"460" should read "460-1000 of an inch."
372	12	"Fig. 9" should read "Fig. 10." ¼
372	15	"Fig. 10" should read "Fig. 9."
383	28	"Fig. 26" should read "Fig. 25."
386	11	"Flown" should read "flowed.'
369	19	"The sum of first by the second, etc.," should read "the sum of the first times the second, etc."
433	3	"Contract strips" should read "contact strips."
435	14	"Armature" should read "Ammeter."
435	20	"L'Arsonval" should read "D'Arsonval."
454	16	"Right hand" should read "left hand."
457	7	"Any hole of second horizontal row" should read "bottom hole of third vertical row."
457	9	"Any hole of bottom row of negative section" should read. "bottom hole of first vertical row of negative section."
457	12	"Circuit No. 1 to machine No. 2" should read, "Machine No. 1 to circuit No. 2."
485	4	"Divided by x the" should read, "divided by the."
492	11	"Un-directional" should read "Uni-directional."
494	28	"Un-directional" should read, "uni-directional."
494	4	"As energize" should read, "are energize."
517	28	"Latter" should read, "former."
288	91	"Advantages" should read "disadvantages."
646	1	"Racking" should read, "packing."

PUBLISHER'S PREFACE

IN placing this book on the market I feel that I am filling a want that has been keenly felt for a considerable length of time by steam and locomotive engineers and firemen, electrical workers and others interested in the subjects whereof it treats. Thirty-four years spent in the sale of technical books has made me fully aware of their faults and limitations, and equally fully aware of the wants of the purchasers of such books.

This book is really a text-book of the St. Louis School of Engineering, the entire mechanical portion, except that pertaining to the locomotive, having been written by Prof. E. Spangenberg, C. E., the Superintendent of that institution, a graduate of the shop and work bench as well as of the University. Mr. Spangenberg has been eminently successful as a teacher, having enabled hundreds of men to pass satisfactory examinations for stationary and marine engineers' licenses.

Mr. E. W. Pratt, author of the portion on Locomotive Engineering, is master mechanic of one of the large railroads, and has made the locomotive his life-study.

Mr. Albert Uhl, A. I. E. E., Instructor in Practical Electrical Engineering at the St. Louis School of Engineering, is a successful electrical contractor who has risen from the ranks, having worked as dynamo-tender and wireman's helper in his younger days.

Owing to the wide experience of these men, they well know the points a book like this must cover to be of greatest service to the men for whom it is written. Their long association with working men enables them to make the explanations in language and terms that are readily understood by working men. In fact, a great portion of the book consists of explanations of apparatus their connections, theory and workings, by one of the authors to a student, friend or employe. Sort of "heart to heart talks," as it were, the kinds which linger in the memory when many another thing is long forgotten.

Owing to this fortunate blending of the practical with the theoretical this work is a library and reference book in the true sense of the word, and will for that reason many times compensate for its purchase and perusal.

Great care has been taken in the preparation of this work, yet errors or omissions may have occurred. We invite communications from readers calling attention to any of these they may find, assuring them that it will be heartily appreciated.

GEORGE A. ZELLER,

St. Louis, U. S. A. *Publisher.*

VAPOR STEAM AIR

Question 1—What do you understand by water vapor?
Answer—Water vapor is water brought into a state equal to that of our common air as it exists in nature.

Question 2—How is this vapor created?
Answer—Water vapor is created by natural heat of the atmospheric air at the water surface; the dryer and warmer the air, the more rapid is the process of evaporation. When water is placed in an open pot, and artificial heat is applied on outside, evaporation takes place at all points where the water comes in contact with the inside of vessel; during this time the water is termed as being in a state of ebullition.

Question 3—What qualities has this vapor?
Answer—Water vapor has the same qualities as the atmospheric air; it is invisible and elastic. By the term "elastic" is meant that it may be expanded or compressed, and will, as soon as the power acting upon it ceases, occupy its original space again. Water vapor accepts the same temperature as the air in which it floats, and carries that of the water from which it originates, only as long as it lies in direct contact with it. The vapor is brought back to the liquid state, when the heat, which was used for its creation, leaves it.

Question 4—What do you understand by water steam? How is it made, and what qualities has it?
Answer—Water steam is created by artificially heating water contained in a closed vessel. Like water vapor, steam is invisible and elastic, returning to a liquid state as soon as it loses the heat by means of which it is created. But unlike water vapor, it always carries a certain temperature and a certain amount of water in itself, both being due to its pressure. Steam may exist under same pressure as the atmospheric air, as well under a higher as a lower one, as long as it is confined; but after being brought into the air, it acquires the pressure and temperature of same, and becomes vapor. The evaporation of water inclosed in a boiler takes place at the water level, and in this case the water makes no ebullitions. Thus the evaporation of the water in a boiler resembles the evaporation of water by natural heat in an open pot.

Question 5—Is the heating of water similar to sweetening or salting it?

Answer—Heat, unlike sugar and salt, is not a material body, and when added to the water gives to it only the qualities possessed by heat, and effects a momentary change of temperature and volume or aggregate of the water but never a permanent one.

Question 6—What characterizes a body or matter?

Answer—A body or matter exists only in three different states or aggregates; either solid, liquid or aeriform. All bodies have weight and occupy space; they also offer more or less resistance when opposed by other bodies or forces.

Question 7—How can it be proven that an aeriform body has these qualities?

Answer—A vessel filled with air weighs more than when the air has been pumped out; and if a glass tumbler is inverted and placed in a basin of water, it will be noticed that the air will not allow the water to enter; this proves that air possesses weight, occupies space and prevents other bodies from entering this space. A certain amount of force is also required to move the air, which may be proven by rapidly moving the open hand to and fro, a certain resistance being noted at each motion.

Question 8—How can we prove that heat does not possess the qualities of a body?

Answer—A bar of cold iron, brought to a red heat, does not show the least increase of weight, despite the fact that large quantities of heat have been added. Heat occupies no space of itself; it will, sooner or later, penetrate any bodies, regardless of resistance, and it will also enter any space, no matter what bodies may be occupying it. A vacuum, that is, a space entirely free of matter, cannot be penetrated by heat. Heat cannot be confined, because it is bound to penetrate the walls surrounding it. It offers no resistance, as, when we pass through it, its presence becomes known to us by our sense of feeling only.

Question 9—Do the terms heat and temperature mean the same?

Answer—No. Temperature is only a quality of heat.

Question 10—How is temperature measured?

Answer—Temperature is measured by instruments which are called thermometers. Such thermometers are represented in Figures 1, 2, 3, Figure 1 shows the Fahrenheit, Figure 2

the Reaumur, and Figure 3 the Celsius thermometer. The following table compares their scales:

F.	R.	C.	F.	R.	C.	F.	R	C.
—40	—32	—40	+ 50	+ 8	+10	+212	+ 80	+100
—22	—24	—30	+ 68	+16	+20	+230	+ 88	+110
— 4	—16	—20	+ 86	+24	+30	+248	+ 96	+120
0	—14,2	—17,7	+104	+32	+40	+266	+104	+130
+ 5	—12	—15	+122	+40	+50	+284	+112	+140
+12	— 8	—10	+140	+48	+ 60	+302	+120	+150
+ 23	— 4	— 5	+158	+56	+70	+320	+128	+160
+32	0	0	+ 176	+64	+80	+338	+136	+170
+41	+ 4	+ 5	+194	+72	+90	+356	+144	+180

It will be noticed, that the boiling point of water is indicated by a different scale number on each thermometer; Fahrenheit placing it at +212°, Reaumur at +80° and Celsius at +100; while the freezing point is set by Fahrenheit at +32°, Reaumur and Celsius mark it 0°. The space between freezing and boiling point is divided by Fahrenheit into 180, by Reaumur into 80, and by Celsius into 100 equal parts, each one of the parts being known as a degree. The scale is extended above the boiling and below the freezing point, and the prefixes + and — denote the temperature in degrees above and below zero, respectively.

Question 11—How is heat measured?

Answer—Heat is measured by the amount of fuel consumed. The amount required to raise the temperature of 61 cubic inches of water which is ice cold for one degree on either of the different thermometers, represents one unit of heat. For example, if we wish to raise the temperature of ice cold water to the boiling point, we would use according to Fahrenheit 180, to Reaumur 80, and to Celsius 100 units of heat. For the purpose of custom and convenience, the Celsius thermometer is used in this book. To heat up 61 cubic inches of water of 0° to 100° it requires, according to the Celsius thermometer 100 units of heat, and the fuel needed for the purpose is equivalent to 100 units of heat.

Question 12—What qualities has heat?

Answer—Heat has the quality to expand bodies, to change their temperature, and to change the aggregate of bodies. It is transferable by contact and also by radiation, it can be reflected, but influences bodies of different natures in different manners.

Question 13—If heat is not considered as a matter, what is it termed?

Answer—Heat is a power.

Question 14—How can you prove that heat is a power?

Answer—We may, for example, place a bar of iron between two heavy bodies, so that it will be held tightly; after applying a certain amount of heat to the iron, we allow it to cool off, and find, that the iron is no longer held in place, but falls to the ground. This is caused by reason of the bodies being moved from their original positions, which can only be done by the application of power.

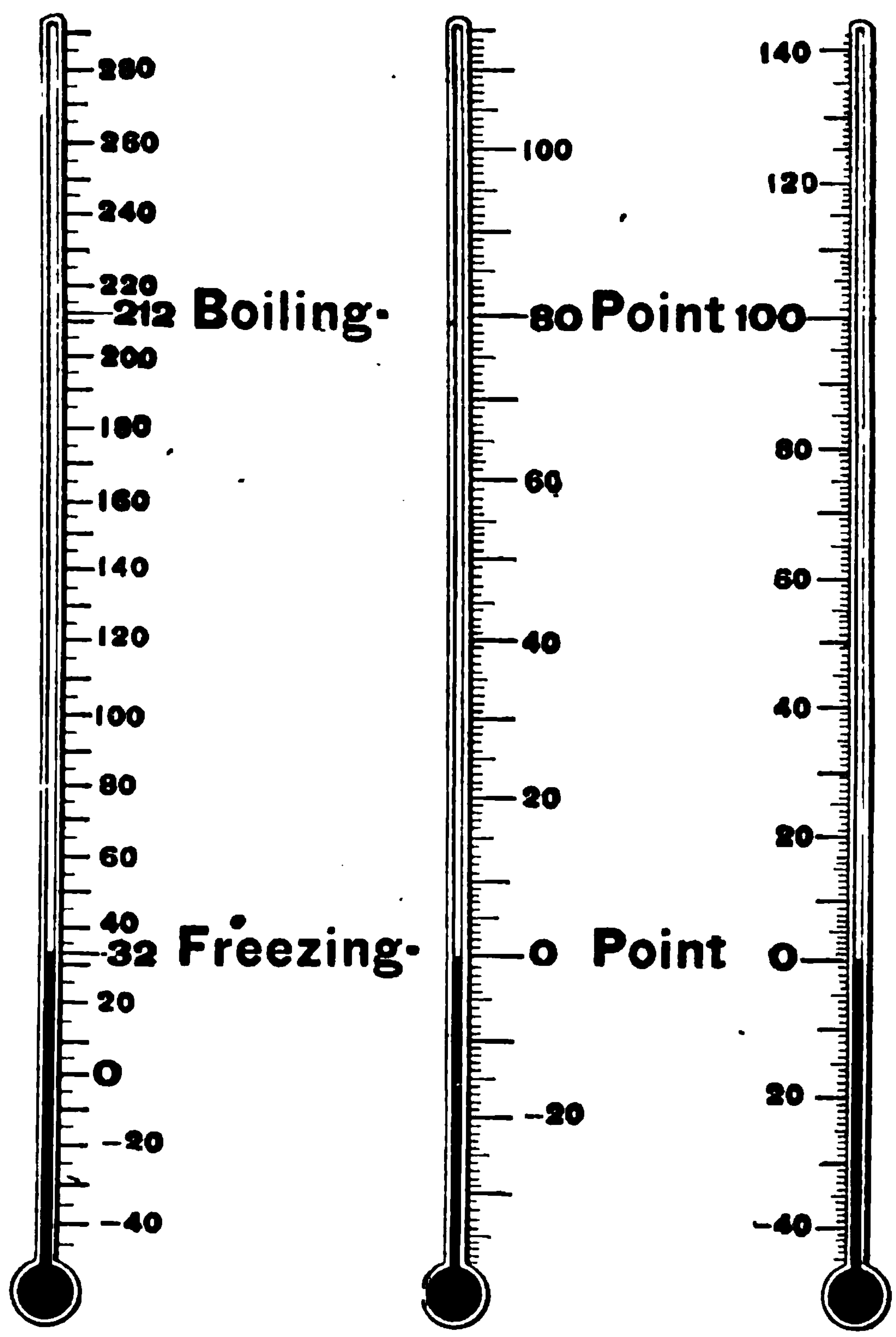


FIG. 1. FIG. 2. FIG. 3.

Question 15—How can heat be developed?

Answer—Heat may be developed by concentrating the beams of light, or by mechanical motion, which may result in friction or compression. Electricity can also be transformed into heat. Any chemical combination of two matters, forming a body different in character from the component parts, develops heat; and a chemical combination of fuel with air is used in steam engineering for the purpose of transferring water into vapor or steam.

Question 16—How does heat influence water when artificially applied to it?

Answer—When heat is applied to an open pot containing water, it at first affects the shell, and is in turn communicated to those particles of water lying next to the shell. These particles are expanded by the heat, and become lighter by increasing the volume of the water; the heated or lighter particle rising to the top, and the colder particles taking their place, thus making a continuous circulation. This circulation can be proven by placing a small quantity of bran on the water, which will be drawn under and raised up by the circulation. As soon as the temperature approaches 70 degrees, particles will appear at the shell in the shape of bubbles, which attempt to rise and then disappear; the water is making a noise called singing. As the water becomes hotter the bubbles ascend higher; when it shows a temperature of 100 degrees and stands under the atmosphere's pressure, the bubbles finally penetrate the surface of the water, which is now in a state of ebullition.

Question 17—What do you understand by an atmosphere's pressure?

Answer—The actual pressure of the air at the level of the ocean is 14.7 lb. per square inch, and we call this one atmosphere's pressure; but commonly we speak of an atmosphere's pressure as equal to 15 lbs. per square inch.

Question 18—How can you prove that air presses, if you can not feel this pressure?

Answer—Weight really represents the amount of attraction the earth has for different bodies, and the power required to overcome this attraction is commonly called the weight of that body. In size the human body, compared to the earth, is much less in ratio than the smallest speck of dust on a foot-ball. We have noted how the rapidly revolving wheels of a vehicle throw off the mud adhering to it; considering the enormously greater speed of the earth we can easily imagine the fate of all bodies on this globe, were they not held there

by an attractive force. We know that all bodies may be separated into smaller portions, the smallest portion into which the body or substance can be divided without changing its nature being called a molecule. Each molecule can be resolved into atoms of the various elements, which, by their combination, form the nature of the substance; the original substance then no longer exists and is said to be decomposed. An atom is an indivisible portion of matter. Molecules are of globular shape and are all equally attracted by the earth, no cutting, tearing, grinding, crushing or other power can alter them. We have stated before that air has weight, and if we consider the fact that a layer of air to the height of 125 miles surrounds this globe, we must acknowledge that the pressure at the bottom of this layer is a considerable one; consequently the action of the air pressure is greater at a point below the level of the ocean, and less above, than it is at the ocean level.

Question 19—How do you measure the pressure of air?

Answer—If we use a syringe of sufficient length, with caliber of one square inch area, fitted with a positive air tight piston, the water will follow this piston when in motion up to a height of 33,885 feet. If instead of water, mercury is used the mercury will follow the piston up to a height of 29.7 inch, and if we weigh the water and mercury, which have been lifted in the syringe to these respective heights, we will find that the water as well as the mercury, weigh exactly 14.7 lbs. To measure the pressure of the air, we use an apparatus called a barometer. Figures 4, 5 and 6 will show the different constructions of them, but all act on the same principle, and will show at the level of the ocean, between the two levels of the mercury a column of 29.9 inch in vertical height. If we go with the same apparatus on a high mountain, a smaller mercury column will be kept in balance, and in a deep mine a greater column. The nearer we come to the center of the globe the higher the mercury column will rise corresponding with the air pressure. The farther we go away from the globe, the lower the mercury column will be, corresponding to the smaller air pressure. If we consider the atmospheric air pressure equal to 15 lb. and the mercury column, which is kept in balance, equal to 30 in., then a mercury column of 2 in., must be equal to 1 lb. of air pressure. When the mercury column shows 28 in. we have an air pressure of only 14 lbs. and if the mercury column shows 32 in., we have an air pressure of 16 lb.; in the first case consequently less, in the latter case more than one atmosphere's pressure. In the Figures 4, 5 and 6, A represents the glass tube into which the mercury is lifted by the atmospheric air

pressure out of the cup B, a reservoir for mercury, and in Figure 5, C is a wooden socket supporting the wooden board D on which the glass tube A is arranged vertically adjustable; this is the best construction, as the difference between the two mercury levels can be read correct. Every barometer must be read while the glass tube is plumb. While only a small variation of air pressure can be indicated by a barometer, its glass tube is generally not made longer than

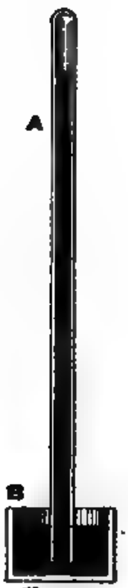


FIG. 4.

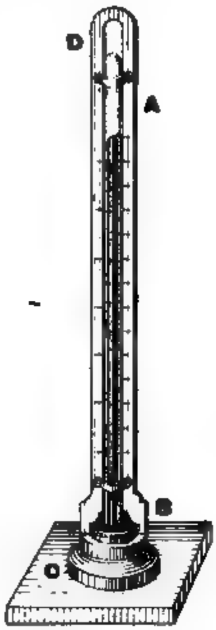


FIG. 5.

FIG. 6.

32 in.; one end of the tube is closed so that it can be entirely filled with mercury, and the open end closed by the thumb, then the tube is reversed, and is handled that the amount of mercury which can not be kept in balance by the air pressure may run into cup B. The closed end of the tube will then show a vacuum.

Question 20—How do you measure the pressure of aeriform bodies when standing under several atmospheres' pressure?

Answer—A higher than one atmospheres' pressure is measured by an instrument called a manometer. The construction and action of this manometer is illustrated by Figures 7, 8, 9, and 10; it is a U shaped tube. The one shank A is open while the other B is closed, as Figures 7, 8 and 9 will show. Figure 7 shows the U shaped tube filled with mercury only so

that the shanks A and B are separated from each other. The air in each of these shanks is consequently equal to one atmosphere's pressure. If we now fill up the shank A to such a height, that the difference between the two levels in the shanks amount to 29.9 in. as shown in Figure 8, we see the air in the closed shank B compressed into half the room it occupied before; the mercury rises in shank B, and the air in shank B, is brought to two atmospheres' pressure. If we add still more mercury, into shank A, until the air in shank B occupies only a third part of its original room, as shown in Figure 9, the air will be of three atmospheres' pressure, and the difference between the two levels of the mercury columns amounts to two times 29.9 inches or 59.8 inches. The atmospheric air pressure acts upon the open shank, and this added to the pressure represented by the mercury column, the sum of these is equal to the pressure of the compressed air. In Figure 10 a manometer is shown in which, instead of atmospheric air, steam acts, in the shank A. Both shanks in this barometer, A as well as B, are open while mercury is poured into it. Both shanks are of the same length, but are half filled with mercury while standing plumb. Then shank B is closed and secured in such a way that no pressure can loosen the cap from its tight seat. The other shank A is so arranged that a steam pipe can be brought in connection with it. While the original air room in shank B contains one atmosphere's pressure, it will contain two atmospheres' pressure if only half this size; three atmosphere's pressure, if only one third this size, and so on. The scale marked Figure 10 shows the variation of the pressure.

FIG. 7. FIG. 8. FIG. 9.

Question 21—Is the boiling point of water influenced by the atmospheric air pressure, and if so, how are you able to prove it?

Answer—The boiling point under one atmospheres' pressure shows 100 degrees by Celsius thermometer. As soon as the pressure of the air is greater, the water must come to a higher temperature before it boils, and if the air pressure

which rests upon the water is less than an atmosphheres' pressure, the boiling point is lower than 100 degrees. An experiment will prove this: Fill a bottle about half with water; set one thermometer in the water and suspend the other in the space above, the bottle being left uncorked. Then place

FIG. 10.

it on a stove, where it will be under a full atmosphere's pressure, for heating. As soon as the water boils, the thermometer in the water shows 100 degrees, and the one laying in the vapor will also indicate the same temperature of 100 degrees. We may continue heating the water, but neither

the water nor the vapor will change in temperature. If we now close the bottle with a cork, and place it on a table, the ebullitions in the water will stop at once, but the temperature of 100 degrees in water and vapor room will remain; next take a sponge moistened with ice cold water, and cool off the vapor room, it will be noted that the water again makes ebullitions without any heat being added; but these ebullitions are more violent than when the water is boiling. During the time that these ebullitions take place the temperature in the water room becomes lower while the cooled off vapor room gains in temperature, and as soon as the two thermometers in water and vapor room show the same temperature the ebullition of the water stops. This process can be repeated several times, and while the vapor, by cooling off is losing part of its pressure, the water commences to bubble again, and creates new vapor. This shows that the lower the pressure resting on the water, the lower its boiling point will be.

Question 22—What becomes of that heat which is added to the water while it is boiling, but shows no increase of temperature on the thermometer?

Answer—It may appear to every one that the heat, which will be added while the water is boiling, is wasted, because neither the water nor the vapor which is lying in contact with it, can ever show a higher temperature than that of the boiling point of the water. But a careful examination will prove that this is not lost; it is necessary that heat be added for the purpose of bringing the water into vapor. Even if the heat which is added to boiling water does not appear in a sensible state, it nevertheless exists, and is necessary to keep the vapor alive.

Question 23—How can it be proven that the heat added after the boiling point of water is reached, is not lost, but lying in the vapor created?

Answer—As already stated, the water stops bubbling, as soon as it is taken from the fire, but shows the temperature of the boiling point of water. Now if the pot in which the water reached the temperature of the boiling point is again placed over the fire, the water will immediately commence to make ebullitions, and the process of producing vapor continues. An experiment made, and illustrated here by Figure 11, will explain the above fully: B will represent here a pot in which 61 cubic inches of ice cold water are placed. In the water room is a thermometer T1, and in the room above, a thermometer T2 is suspended. The pot is covered, and the pipe S transfers the created vapor very nearly to the bottom of a water tube C in which 5½ times 61 cubic inches ice cold water

are placed. In this water a thermometer T is also suspended. Below the pot B an alcohol lamp F is placed, which is made of glass in cylindrical shape of equal caliber, so that equal distances represent equal amounts of alcohol. The Figure represents this lamp filled up to a point marked zero. Now if the wick of this lamp is lighted, the flame which lies against the bottom of the pot gradually warms up the water in it, and when the water commences boiling, we will make the mark 1 at a point where the alcohol is now standing. The space between 0 and 1 will represent the amount of alcohol consumed, and contains 100 units of heat, while the water is raised to the temperature of 100 degrees. As soon as the water commences boiling, the room above the water fills up with vapor, which in a short time will show the same temperature as the water, 100 degrees. While the water continues to boil, the vapor passes through the pipe S, and enters the water in the tube C in the shape of air bubbles, but these will soon disappear turning into water again by giving up their heat to the water lying in tube C. More and more alcohol will be consumed now, and next we make a scale on the lamp, each part representing the distance which we found before, to be equivalent to 100 units of heat As soon as we have used $6\frac{1}{2}$ times such parts of alcohol, which will represent 650 units of heat, the last drop of water in the pot B disappears, and we find the water which before had been contained in pot B now transferred to the water tube C, and these $6\frac{1}{2}$ times 61 cubic inches of water, used for the experiment, now show 100 degrees. This experiment being made under an air pressure of one atmosphere, proves that none of the heat, expended on the water after the same commenced boiling, and not appearing sensible in the vapor, either to us or the thermometer, was lost; it had only been bound up in the vapor as long as this existed as such, and became free and sensible again after the vapor fell back into its aggregate of water; because we find the 650 units of heat spent for the evaporation of one part of ice cold water transferred to the $6\frac{1}{2}$ parts of water of 100 degrees.

FIG. 11.

Question 24—Does it always require 650 units of heat to evaporate 61 cubic inches of ice cold water if the water is standing under different kinds of pressure than one atmosphere?

Answer—It is immaterial under what pressure the air stands which is resting on the water; it will always take 650 units of heat to evaporate 61 cubic inches of ice cold water.

Question 25—How can we prove that the same amount of fuel is required to transfer a certain quantity of water into vapor even if the air pressure differs?

Answer—If we take the apparatus explained in Fig. 11 into a deep mine, where the water may boil at a temperature of 105 degrees, we will see by repeating the experiment, that 105 units of heat represented by alcohol bring the water to the boiling point; but as soon as the whole 61 cubic inches of ice cold water in the apparatus are evaporated, the alcohol lamp will show that 650 units of heat are consumed. If we take this same apparatus to a high mountain, where the water may be brought to the boiling point at 95 degrees, it shows a consumption of alcohol equal to 95 units of heat when its boiling point is reached, while by a consumption of 650 units of heat, the last drop of water disappears out of pot B, this proves that even though the pressure resting on the water may vary the same amount of fuel is always required to evaporate a certain amount of water; or in other words, every 61 cubic inches of ice cold water at all times need 650 units of heat, under whatever pressure the water is standing. We will add: that, while making the experiment at the bottom of a mine, it is shown that the whole $6\frac{1}{2}\times61$ cubic inches of water, increased in volumn by the temperature of 100° of Celsius have been transferred to the vessel C. Now if we go to a high mountain, we find that we have not the same quantity of water in vessel C, because the water begins to boil at 95° and therefore a certain amount is lost by evaporation into the atmosphere, before the transfer is completed.

Question 26—How do you calculate the number of pounds of soft coal required to evaporate one cubic foot of ice cold water.

Answer—In a well constructed fire place, and by reasonable firing, we can utilize out of a medium good soft coal an average of 1775 units of heat. Now for each 61 cubic inches of ice cold water, we use for evaporation 650 units of heat, therefore for one cubic inch, the 61st part of 650, and for a cubic foot, which is equal to 1728 cubic inches, 1728 times as many units of heat; and as often as 1775 units of heat are contained in the result, so many pounds of soft coal are needed. Or $650\div61\times1728\div1775=10.37$ lbs. of soft coal. We may say that $10\frac{1}{2}$ lbs. of soft coal by reasonable firing, in a good con-

structed fireplace, must be a sufficient average to evaporate one cubic foot of ice cold water.

Question 27—What do we call the heat which is not sensible in water after it has reached the boiling point, but is still necessary to bring about evaporation?

Answer—The heat bound up in vapor, as long as this vapor exists, may, as explained before be developed again, and we therefore call this latent heat. Therefore, water which starts its evaporation at 95 degrees, carries as vapor in itself 95 units of heat sensible, and 555 units of heat latent; water which starts its evaporation at 100 degrees carries as vapor in itself 100 units of heat sensible, and 550 units of heat latent; water which starts its evaporation at 105 degrees, carries as vapor in itself 105 units of heat sensible, and 545 units of heat latent, while the sum of sensible and latent heat in vapor of any kind of pressure must always be 650.

Question 28—What influence has heat when applied to water in a boiler?

Answer—When heat shall be applied to water in a boiler, by which is understood a closed vessel, a cock should be opened to allow the discharge of the air in the boiler, because air has a tendency to corrode the iron when moist. The heat applied to the shell of a boiler will be transferred through it to the water, same as in an open pot; the heated water particles rising, and the cold particles taking their place. The water will also circulate in the boiler, and when it reaches a temperature of about 70 degrees, the water commences singing, and at 100 degrees, when we have a full atmosphere's air pressure, the water boils, and the vapor leaves the boiler, driving the atmospheric air out through the before mentioned open cock; this vapor, as soon as it comes in contact with the atmospheric air will be cooled down and appears partly as fog, which is nothing else than a great number of very fine water particles, but no longer vapor. As soon as this fog appears the cock can be closed, and the vapor is now confined in the boiler as steam of one atmospheres' pressure; but the evaporation continues, the vapor receiving a greater density, and therefore acts with more than one atmosphere's pressure on the water; the ebullitions in the water will now stop, since the vapor bubbles created at the shell can no longer penetrate the water level. The water and steam reach a higher temperature the longer we continue the evaporation, and so the steam increases in density and pressure; the latent heat which is needed for the evaporation comes to a rest at the top sheet of the water, and makes this, as we say, steam ready, and the vapor created, which we now call steam, will leave the level

of the water in the boiler by careful handling of the latter in a similar way, sheet by sheet, as it may be needed, same as dealing cards.

Question 29—Is the temperature of steam the same under various pressures?

Answer—To find this out, we may place a thermometer in the glass gauge, which is used on every boiler to show us its water level, and apply to the boiler at its steam room a manometer, as described in Figure 10. By comparing the thermometer with the manometer, we will find that, while steam of one atmospheres' pressure shows a temperature of 100 degrees, that of two atmospheres' pressure, shows 121.5 degrees, that of three atmospheres' 135 degrees, that of four atmospheres' 144.95 degrees, that of ten atmospheres' pressure shows 181 degrees. This proves, that steam of different pressures has different temperature, and that to each steam pressure a certain temperature is required; it also proves that the higher the steam pressure, the higher will be the temperature, but while the pressure is increasing in equal proportion, the corresponding temperatures are retarded in their increase.

Question 30—What volume of steam can be made out of one cubic inch of water of zero degrees under various pressures?

Answer—The following table will illustrate answer:

Number of Atmospheres.	Degrees of Celsius.	Number of Cubic Inches of Steam made out of 1 c″ of water of 0°	Pressure in pounds per Square inch.
.125	51.45	11798.213	1.837
.25	66.00	6164.684	3.675
.50	82.00	3228 364	7.35
.75	90.00	2213.041	11.025
1.	100.00	1696.320	14.7
1.25	106.60	1381.149	18.375
1.50	112.40	1168.508	22.05
1.75	117.10	1013.812	25.725
2.	121.50	897.214	29.4
2.25	125.50	805.620	33.075
2.50	128.85	731.683	36.75
2.75	132.15	669.178	40.425
3.	135.00	618.677	44.1
3.25	137.70	574.819	47.775

Number of Atmospheres.	Degrees of Celsius.	Number of Cubic Inches of Steam made out of 1 c″ of water of 0°	Pressure in pounds per Square Inch.
3.50	140.35	537.291	51.45
3.75	142.70	504.362	55.125
4.	144.95	475.358	58.8
4 25	146.76	449.394	62.475
4.50	149.15	426.704	66.15
4.75	151.15	406.176	69.825
5.	153.30	387.907	73.5
5.50	156.70	355.379	80.85
6.	160.00	328.352	88.2
6.50	163.25	305.376	95.55
7.	166.45	285.649	102.9
7.50	169.40	268.400	110.25
8.	172.10	253.165	117.6
9.	177.40	227.723	132 3
10.	181.00	206.593	147.
11.	186.05	189.907	161.7
12.	190.00	175.584	176.4
13.	193.70	163.376	191.1
14.	197.19	152.844	205.8
15.	200.48	143 655	220.5
16.	203.60	135.566	235.2
17.	206.57	128.389	249.9
18.	209.40	121.974	264.6
19.	212.10	116.202	279.3
20.	214.70	110.985	294.
25.	226.30	90.906	367.5
30.	236.20	77.660	441.
35.	244.85	67.351	514.5
40.	252.55	59.810	588.
50.	265.89	49.066	735.

Question 31—How do we estimate the effect of a power?

Answer—By every piece of work that is done, a weight must be moved a certain distance, and when 100 pounds are moved through a distance of 10 feet, it is the same as if 10 pounds where moved a distance of 100 feet. The product of distance and weight consequently gives the amount of work done; but to judge the effect and value of this work, it is of material necessity to take into consideration the time consumed. It is understood, whenever we move one pound a distance of one foot, in a second's time, that this represents a foot-pound. Whenever we move 100 pounds a distance of 50 feet in 20 seconds' time, the effect of the work will be 100 times 50, divided by 20, equal to 250 foot-pounds. If we have a great number of foot-pounds and divide them by 542, we say we have a horse power as a result; for instance, to move 2,000 pounds a distance of 500 feet in 20 seconds' time, we calculate the result in horse power, by multiplying 2,000

by 500 and dividing this product by 20 and by 542, this is: $2000 \times 500 \div 20 \div 542 = 92.25$ horse power.

Question 32—How can we calculate the power which is lying in steam?

Answer—If we have a pipe of one square inch area, and a piston placed therein, the piston cannot be brought in motion while an equal pressure is acting on both sides of it; but as soon as we have more pressure acting on one side, than on the other, the piston moves by the aid of its over-pressure in that direction in which the smaller power is lying. If this over-pressure amounts to one pound, and the piston of one square inch area is moved through a distance of one foot in one second's time, 12 cubic inches of steam of one pound over-pressure being used, then we have the effect of one foot pound. Out of this we can follow:

when	12 c″ of 1 lb.	$\left\{ \text{over-pressure steam used in 1 second's time.} \right\}$	=	1 lb.
then	1 c″ of 1 lb.	"	=	$^1/_{12}$ lb.
	1 c″ of 50 lb.	"	=	$^{50}/_{12}$ lb.
	480 c″ of 50 lb.	"	=	$480 \times {}^{50}/_{12}$ lb.

=2000 ′lb.

Consequently, to express the power which is lying in foot pounds, we multiply the number of cubic inches of steam used in a second's time by the twelfth part of its over-pressure; and to express in horse power, we divide the foot-pounds by 542. Thus we make in a second's time 1 foot-pound, and in a minute 60 foot-pounds; then 60 times 542 equals 32520, being the foot-pounds contained in a horse-power per minute. To simplify calculations, the figures 32500 are adopted throughout the civilized world. We now express the formula to find the horse power in steam: Multiplying the number of cubic inches steam used in a minute's time by the twelve part of its over-pressure, and divide the product by 32500.

Question 33—How do you calculate the number of cubic inches of steam accumulated in an engine in a minute's time?

Answer—Given the diameter of piston in inches, the length of its stroke in inches, and the number of revolutions which the engine makes in a minute, first calculate the area of the piston and multiply by the length of the stroke; this gives the number of cubic inches of steam contained in the cylinder; and while the engine uses two cylinder fillings per revolution, the contents of cylinder must be multiplied by 2 and then by the number of revolutions per minute.

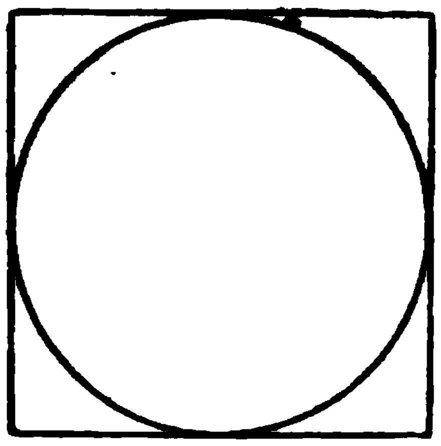


FIG. 12.

Question 34—How is the area of the piston found?

Answer—Multiply diameter by itself and either by 11/14 or by .7854; that is, find the square which can be erected on the diameter of the piston first, and the circle will be the above mentioned fraction of the square. (See Fig. 12.)

Question 35—How much horse-power is accumulated in an engine with 100 lbs. over-pressure of steam, when number of revolutions per minute is 65, the diameter of the piston is 21 inches, and its stroke is 30 inches? And what special name do we have for this horse power?

	21×21×.7854	×30	×2	×65	×100		= 346,3614
Square inches area of piston.					12	×32500	*nominal* horse power.
c″ contents of cylinder, - - - - - -							
c″ steam used per revolution, - - - - -							
c″ steam used per minute, - - - - - - - - -							
Pounds accumulated in engine, - - - - - - - -							
Horse power accumulated in engine, - - - - - - - - - -							

Or, if we use instead of a decimal fraction, the common fraction, we have:

$$\frac{21\times21\times11\times30\times2\times65\times100}{14\times12\times32500}=346\tfrac{1}{2}\ \textit{nominal}\ \text{horse power.}$$

The small difference in these two calculations proves that, for finding the area of a circle is immaterial if we multiply the square of the diameter by $\frac{11}{14}$, or by .7854.

Question 36—By changing the number of revolutions or the over-pressure of steam, or both, the same engine will show different nominal horse power; yet, there must be some standard rule for manufacturers and dealers to express the average horse-power their engines are capable of. What is this standard rule and what special name is given to the horse-power?

Answer—The manufacturer or dealer expresses the product of revolutions times over pressure, by the standard figure 6000, and calls the result of his calculation, the *commercial* horse-power of an engine. So the engine mentioned in the last question will show:

$$\frac{21\times21\times11\times30\times2\times6000}{14\times12\times32500}=319.8461\ \textit{commercial}\ \text{horse power.}$$

Question 37—Can the full nominal horse-power of an engine be transferred to other machines?

Answer—An engine uses up 25 per cent of the accumulated power by friction, a further 12½ per cent is lost by transferring the straight motion of the piston rod into the rotary one of the crankshaft, and 5 per cent of the power is lost by the cooling off of steam at each stroke, so that the total loss under all circumstances will be 42½ per cent, and the effective power transferred to other machines can only be 57½ per cent. If we divide the before made calculation of nominal horse power by 100 and multiply by 57½, we will have the *effective* horse power, thus:

$$\frac{21\times21\times11\times30\times2\times65\times100\times57.5}{14\times12\times32500\times100}=199.2376 \text{ \textit{effective} horse power.}$$

Question 38—What is understood by real pressure steam?

Answer—Real pressure steam is compared in a ratio to the atmosphere's pressure. We understand by 10 atmospheres' real pressure steam, that the pressure of this steam is ten times that of one atmosphere's steam pressure. The table which shows us the difference in volume of steam of different pressures, represents real pressure steam.

Question 39—What is meant by over-pressure steam?

Answer—Over-pressure steam in a boiler always means one atmosphere less than the real pressure steam contained in it; because the outside pressure on a boiler is the atmosphere's air pressure. But whenever we intend to calculate the power of steam, acting in an engine, we must recollect that at times one atmosphere's air pressure is acting against the steam pressure in an engine, and that at other times more or less than an atmosphere's pressure may act against the real pressure in an engine; therefore the counteraction deducted from the real pressure steam, leaves the over-pressure acting in an engine.

Question 40—What do we understand by low pressure steam and what by high pressure steam?

Answer—These two expressions are applied more to boilers than to engines. We talk of a low pressure boiler, where it is intended to be used for hoisting purposes, as it requires only a small over-pressure which will never exceed more than one atmosphere's over-pressure. A high pressure boiler is used for power purposes, to drive steam engines or steam machines, and has at least three atmospheres' over-pressure to withstand. These expressions, "high and low pressure," are now-a-days used only when referring to steam cylinders of that class of engines, called compound engines.

Question 41—What does full pressure mean?
Answer—We say the engine is running under full pressure, if the steam cylinder waives steam of equal pressure during the whole stroke.

Question 42—What is meant by back-pressure steam?
Answer—When the steam which had been used for one stroke, cannot entirely escape during the reverse stroke, and part of it remains, it must be compressed and therefore cause a greater counteraction; this is generally called back-pressure steam, but really every counteraction in a steam cylinder is caused by back-pressure.

Question 43—What is saturated steam?
Answer—Steam which carries in itself the right amount of water, and the right temperature, which are due to its pressure, is called saturated steam. The figures shown in table under question 30 refer to saturated steam.

Question 44—What is the meaning of surcharged steam?
Answer—It is the steam which carries in itself more water than due to its pressure.

Question 45—What is the meaning of superheated steam?
Answer—It is the steam which carries in itself a higher temperature than due to its pressure.

Question 46—What is the meaning of live steam?
Answer—Live steam is that which arrives at the engine, machine or apparatus in which it is to be used, with the same pressure as when it was originated, being in no wise weakened by its passage.

Question 47—What do we understand by dry steam?
Answer—Dry steam is the same as the saturated or superheated steam; it carries no water particles with it.

Question 48—What do we understand by wet steam?
Answer—It is steam which carries water particles along, and is consequently the same as surcharged steam.

Question 49—What is expanding steam?
Answer—If steam, after it passed from the boiler to the cylinder of an engine, is cut off by the admitting valve before the cylinder is entirely filled (or, in other words, before the piston finishes a full stroke), the steam is bound to expand; the over-pressure lying in the steam is exerting its power against the piston, and, though the power is gradually weakened, the piston is still enabled to continue the stroke until the over-pressure is absorbed, or the reverse stroke is caused.

Question 50—What do you understand by wire-drawn steam?

Answer—When steam, on its way to the apparatus or engine in which it shall be used, is made to increase its volume by being conveyed from a small pipe to one of larger diameter, or, in other words, if it is passed from a small room into a large one, it is called wire-drawn steam, because its power will be weakened without giving us any advantage.

Question 51—What do we understand by throttled steam?

Answer—When steam, in its passages from the boiler to the engine, is more or less obstructed by a movable contrivance (as a valve), it is weakened by such obstruction, because it passes from a small opening into a larger one; then we have no advantage of the power so lost, and we call this steam throttled.

Question 52—What is exhaust steam?

Answer—It is steam which has lost its over-pressure, either by coming in contact with the atmospheric air at the moment of its discharge, in which case it has no more pressure than the atmospheric air; or if it is under the influence of a condenser, its over-pressure is still further reduced; in the latter case the real pressure of the acting steam may be less than one atmosphere.

Question 53—What is condensed steam?

Answer—It is steam which has lost its latent heat, and so becomes water.

Question 54—What is compressed steam?

Answer—It is steam forced from a large room into a smaller one, thereby gaining in pressure and temperature.

Question 55—What is counter steam?

Answer—Whenever we have engines, the direction of which can be changed, as hoisting engines, locomotives and marine engines, and the speed of these engines is so great that they cannot be stopped quick enough to prevent an accident, we reverse the action of the engine, and say we give it counter steam.

STEAM GENERATORS

Question 56—What conditions must be filled in the construction of a boiler?

Answer—The material used should be strong enough to resist the strain caused by steam pressure; further, it must have the necessary elasticity to spring back in its original shape when temperature or pressure has changed its size; the shape of the boiler must be such that it can never be changed by

the various pressures; the joining of the different parts must not be neglected in calculating the thickness of the material to be used; and the material must be malleable so that joining of pieces or repairing can be easily attended to. The construction must be so that the circulation in it cannot be obstructed or trapped, and a sufficient steam room must be provided for.

Question 57—What materials can be used for the construction of a boiler?

Answer—Only wrought iron, steel or copper should be used for the construction of a boiler; to a certain extent rolled brass may be used, but never cast brass or cast iron, as both are too brittle and give no guarantee that they contain no air or sand holes, which would make the calculation of their thicknes problematic.

Question 58—What strain should the material which shall be used for boiler construction be able to withstand, and how can it be found that a material possesses the required resistance?

Answer—In figuring the strain which the material is able to withstand, we cannot be governed by the amount of load it will sustain before pulling it apart in the direction of its fibers (called tensile strength), because one-third of this load already destroys the material's elasticity, and material without elasticity should not be used; therefore it should be required to have less than one-third the strength, in fact, never more than one-quarter should be allowed for solid material, and when the material is weakened by seams, a further reduction must be made. But no material should be used in a boiler unless it has a tensile strength of at least 60.000 pounds per square inch section.

Question 59—How must the material be prepared for boiler construction?

Answer—The material is first rolled out in sheets, cut to the different sizes as needed, and brought in the desired shape; these single parts are then joined by seams, which may be either brazed, welded, or riveted. Brazing is used only on copper or brass tubes; welding is made for boiler purposes so that the ends to be joined, form a lapping seam. But welding is not allowed in boiler constructions. Rivet seams are made in one, two, or even more rows.

Question 60—Which must be considered as the best and strongest shape for boiler construction?

Answer—Flat sheets are well enough supported at their edges, but the pressure of the steam, acting at the middle of the sheet, will change its shape. Where the use of flat iron is

absolutely necessary, these parts must be otherwise strengthened. The circular shape is the best, because each point of the circumference is equally supported, therefore, the cylindrical shape is found in general use; pressure and temperature may expand the size, but will never change the shape.

Question 61—How far apart must rivets be set in boiler seam?

Answer—The diameter of the rivet head is twice the diameter of the rivet, and while the rivets shall close the seams tight, we have no right to use a larger space between two rivet heads than the diameter of a rivet head; therefore the cen-

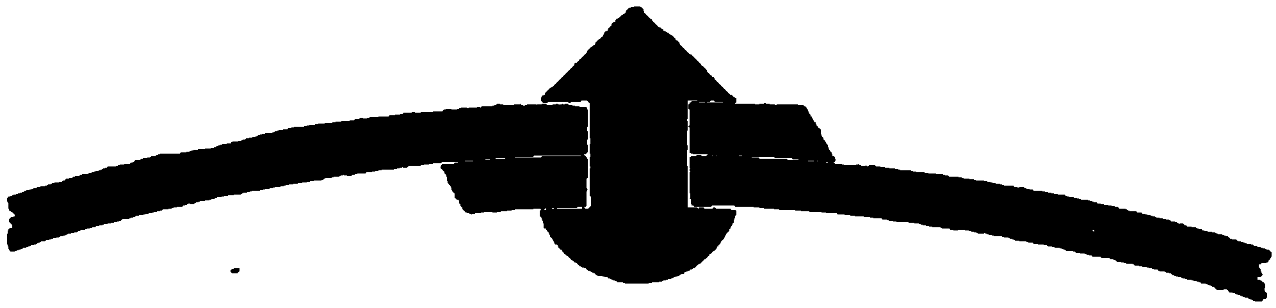


FIG. 13.

ters of the rivet holes must not stand in greater distance from each other than four times the diameter of a rivet. These close distances between the rivet holes weaken the boiler construction considerably, therefore double-riveted

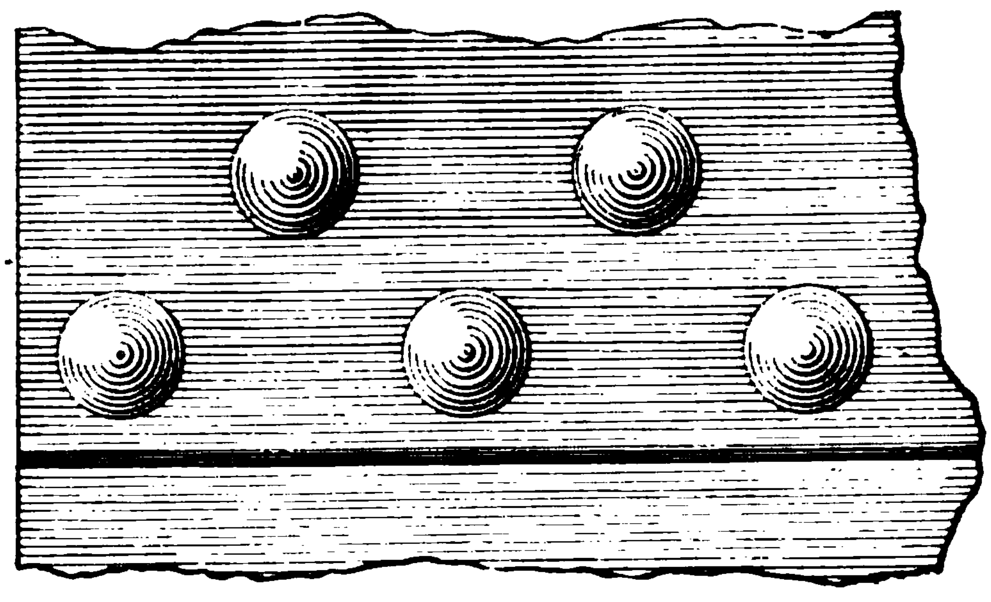


FIG. 14.

seams are preferred under certain circumstances. The two rows will then be placed in zigzag shape, so that the nearest rivet holes are standing with their centers in a distance of four times the diameter of a rivet hole. Figure 13 represents

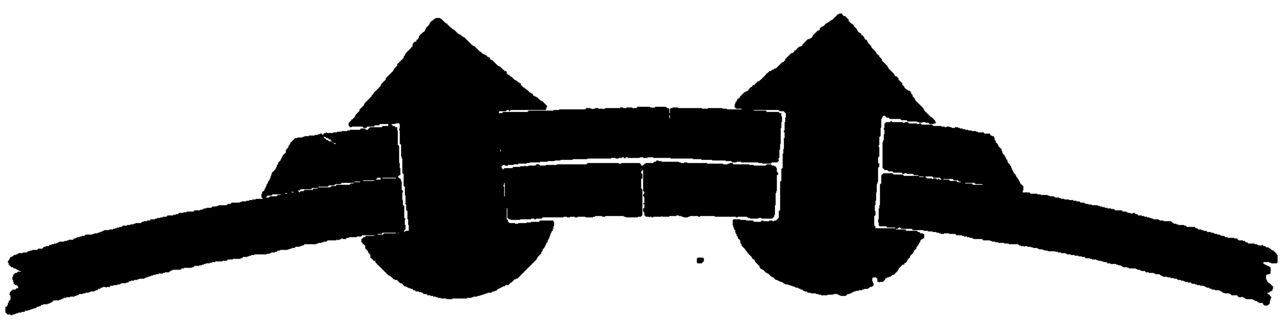


FIG. 15.

a single-riveted seam, while Figure 14 shows a double- riveted one. Figure 15 shows part section of a boiler with two single-riveted rows, but the ends of the sheets do not lap over each other; they are abutting. A small extra sheet of iron, corresponding in shape with the circumference of the boiler, is joining the ends of the sheet by means of rivets.

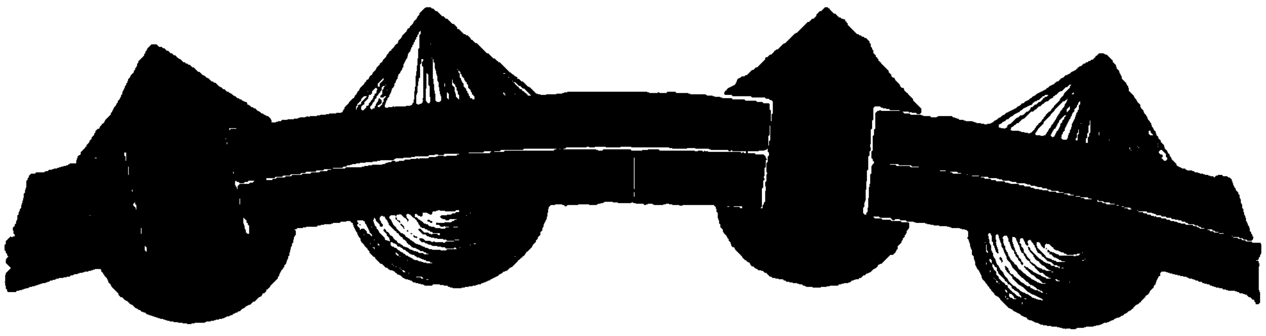


FIG. 16.

Figure 16 shows the same conditions, with two double-riveted rows. The iron, by means of which the joining is effected, is placed on the outside of the boiler, and allows a perfect inner circular shape and makes the pressure act equally on every part of the so riveted shell, and is therefore preferable to the ordinary lap seam.

Question 62—Is it allowed to load a boiler with the pressure per square inch, equal to the tensile strength of the boiler?

Answer—The elasticity of a material is lost by a much smaller load than its tensile strength represents, and as seams further weaken the solidity of the material, these must also be considered. These two facts lead to the conclusion that the tensile strength of a material cannot be used as a load limit on the boiler.

Question 63—By what load and how do we lose the elasticity of the material used for boiler construction?

Answer—While the test for tensile strength of the material is made, it will be seen by loading the bar gradually, that it will be lengthened, and will return to its original shape as soon as the load is taken off, as long as the material retains its elasticity; but as soon as the load is equal to a third part of the tensile strength of the material, its elasticity is lost. This proves that not even a third part of the tensile strength can be allowed for use in a boiler construction, since the seams tend to weaken the material still further.

Question 64—What part of the tensile strength of the material used in the construction of a boiler can be taken with safety as the load per square inch?

Answer—For solid material or for lap-welded iron, we can use a fourth part of the tensile strength as the load; for double-riveted seams only one-fifth part, and for single-riveted seams only a sixth part of the tensile strength.

Question 65—What must be considered when making calculations for the dimensions of a boiler?

Answer—Steam, considered as elastic matter, is able to expand in every direction. If we consider steam entering a pipe in its center, the steam will expand from the center towards the periphery (which is the circumference of the circle), momentarily going in power. To arrive at the full power exerted by the steam at the edge of this circle, we multiply the initial pressure by the radius; this power must be surbound by a wall, able to resist it. Should we use a shell of one inch thickness, counting that part of the tensile strength, which we are allowed to use, and find that this gives us, for instance, five times more resistance than the action the steam pressure requires, then we need only use the fifth part of an inch for the thickness of that shell. The rule for the calculating of the dimensions of boilers is, therefore: The product of radius of cylinder (in inches), multiplied by the safe working pressure (in pounds), must be equal to the product of the thickness of the shell (in inches), multiplied by that part of the tensile strength which must be used to conform to the acquired seam (in inches). But this rule is based on the condition that the cylinder is not longer than five times the diameter of it, and that circle must be considered the surface against which the steam pressure is acting. If we denote the radius as R, the safe working pressure as P, the thickness of shell as T, and that part of tensile strength which (according to the kind of seam used) is required as S, then we may express the above rule by the following formula: $R \times P = T \times S$.

Question 66—What is the safe working pressure of a boiler of 60 inches inside diameter, made of $\frac{1}{4}$ inch iron sheets of 66,000 lbs. tensile strength, with single-riveted seams?

Answer—Substitute in the formula $R \times P = T \times S$ the given values, and receive as result $30 \times P = \frac{1}{4} \times 11{,}000$, which shows for one pressure:

$$\frac{1}{4} \times 11{,}000 \div 30 = \frac{11{,}000}{4 \times 30} = 91.66 \text{ lbs. per square inch.}$$

Question 67—What thickness of shell must be used for a boiler, the inner diameter of which shall be 42 inches, when its safe working pressure shall be 150 pounds per square inch, and the material used shall be steel, double-riveted, and of 75,000 pounds tensile strength?

Answer—These values inserted into the formula $R \times P = T \times S$, show $21 \times 150 = T \times 15{,}000$, or:

$$T = 21 \times 150 \div 15{,}000 = \frac{21 \times 150}{15{,}000} = \frac{21}{100} \text{ inches.}$$

Or, .21 inches thickness needed for the steel sheets.

Question 68—What inner diameter must be given to a cylindrical boiler, when sheets of 60,000 pounds tensile strength and .27 inches thickness shall be riveted in a single row, the boiler to bear a safe working pressure of 135 pounds per square inch?

Answer—These values inserted into the formula $R \times P = T \times S$, will give $R \times 135 = .27 \times 10{,}000$, or:

$$R = .27 \times 10{,}000 \div 135 = \frac{.27 \times 10{,}000}{135} = 20 \text{ inches,}$$

the diameter will consequently be 40 inches.

Question 69—What tensile strength must the material have for a boiler of 54-inch inner diameter, using ¼-inch sheets single-riveted, to bear a safe working pressure of 120 lbs.?

Answer—These values inserted into the formula $R \times P = T \times S$, shows $27 \times 120 = \frac{1}{4} \times S/6$, or $27 \times 120 = 1/24 \times S$, or: $S = 27 \times 120 \div 1/24$; the result is: $S = 27 \times 120 \times 24 = 77{,}760$ pounds.

Question 70—How must the calculation be made for a cylindrical shell, when its length is more than five times its diameter?

Answer—The result which we found by the rule $R \times T = T \times S$, must be multiplied by the number which shows how often the *allowed* lengths are contained in the *needed* lengths.

Question 71—Of what thickness must the shell of a 4-inch lap-welded tube of 30 feet length be, the material to have a tensile strength of 60,000 pounds standing under 150 pounds steam pressure?

Answer—If in the formula, $R \times P = T \times S$, the above values are substituted, we receive, $2 \times 150 = T \times 15{,}000$, or $T = 2 \times 150 \div 15{,}000$. The result must now be multiplied by $(30 \times 12) \div (5 \times 6)$. We now have:

$$T = \frac{2 \times 150 \times 30 \times 12}{15{,}000 \times 5 \times 6} = .24 \text{ in. thickness.}$$

Question 72—What types of boiler construction are in use?

Answer—There are really only three different types: 1. The single shell boiler. 2. The flue boiler, under certain conditions; also called fire tubular boiler. 3. The water tubular boiler.

Question 73—What constitutes a single shell boiler?

Answer—The type of a boiler has nothing to do with its shape. Any kind of shape may be used for single shell boiler. These different shapes may be box-shaped, like Figure 17, trunk-shaped like Figure 18, ball-shaped like Figure 19, egg-

FIG. 17. FIG. 18.

FIG. 19. FIG. 20.

shaped like Figure 20, or cylindrical-shaped like Figure 21 on page 35? All these figures show a single shell boiler, which is characterized by surbinding one room, which is neither perforated by pipes, nor has it any projections or extensions from this simple shell.

Question 74—Under what circumstances would you call a boiler a flue boiler, and when a fire tubular boiler?

Answer—They are both boilers in which a part of the main shell is perforated with pipes laying from one end, through the boiler, to the other end. When these pipes have a riveted seam, we call them flues, and the boiler in which they are inserted, a flue boiler. When the seams of the pipes are lap welded, we call them tubes, and when these tubes extend

through the boiler room, and are fastened to the main shell at opposite ends, the boiler is called a fire tubular boiler. In both constructions heated gases pass through either the flues or tubes, and water surrounds them. Figure 22 shows a flue boiler, Figures 23, 24, 25 and 26 show fire tubular boilers in sectional view.

FIG. 21.

Question 75—What do you understand by water tubular boilers?

Answer—When tubes extend from or if they lie parallel, or on an incline to the main shell; or if smaller boilers are arranged below the main shell, all the above communicating with the main shell, such boilers will be called water tubular boilers. In this construction, the water is contained in the tubes and surrounded by the heated gases. Figures 27, 28, 29, 30 and 31, represent water tubular boilers in sectional views.

Question 76—How are flues and tubes measured, and in what diameters are they usualy made?

Answer—Flues and tubes are always measured by their outside diameter. The smallest size flues made are six inches in diameter and they vary in sizes of one inch. The smallest size tube is made one inch in diameter, and the sizes vary by degrees of one-quarter inch to four inches. Between four and five inches we have only a four and one-half inch diameter; above five inches they vary by one inch degree in

diameter, but seven-inch is the largest size generally used for boiler construction. Larger tubes are made, but mainly used for transferring water under high pressure.

Question 77—How does the thickness of the shell of tubes vary?
Answer—It varies by the wire gauge standard; the thinnest shell is equal to the standard wire-gauge number 15.

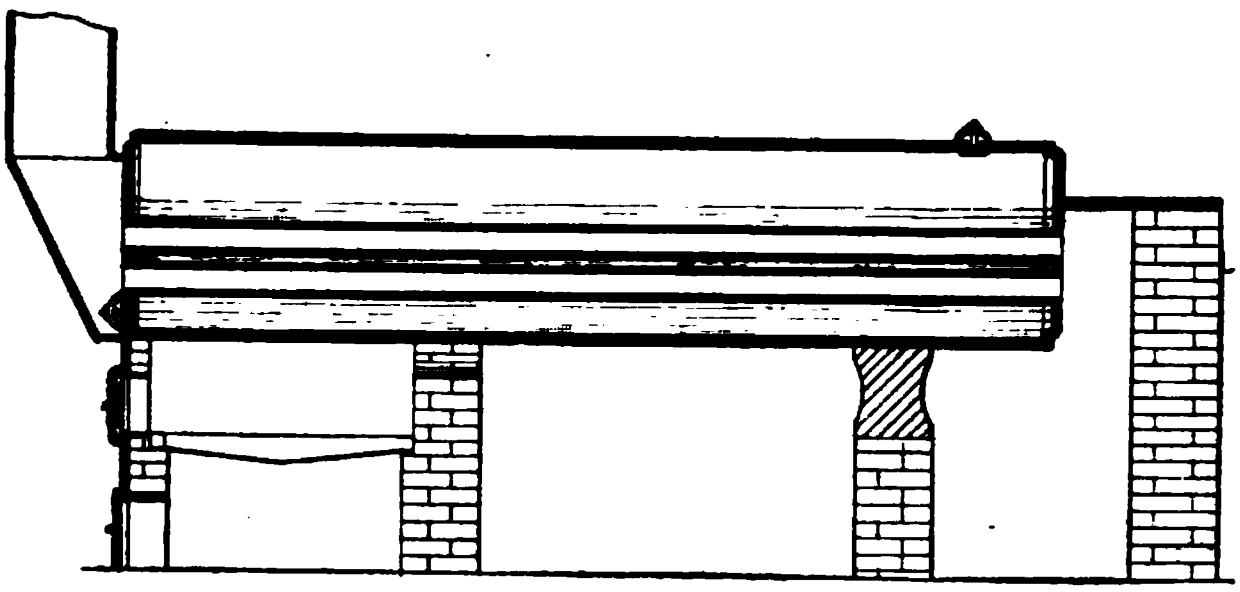


FIG. 22.

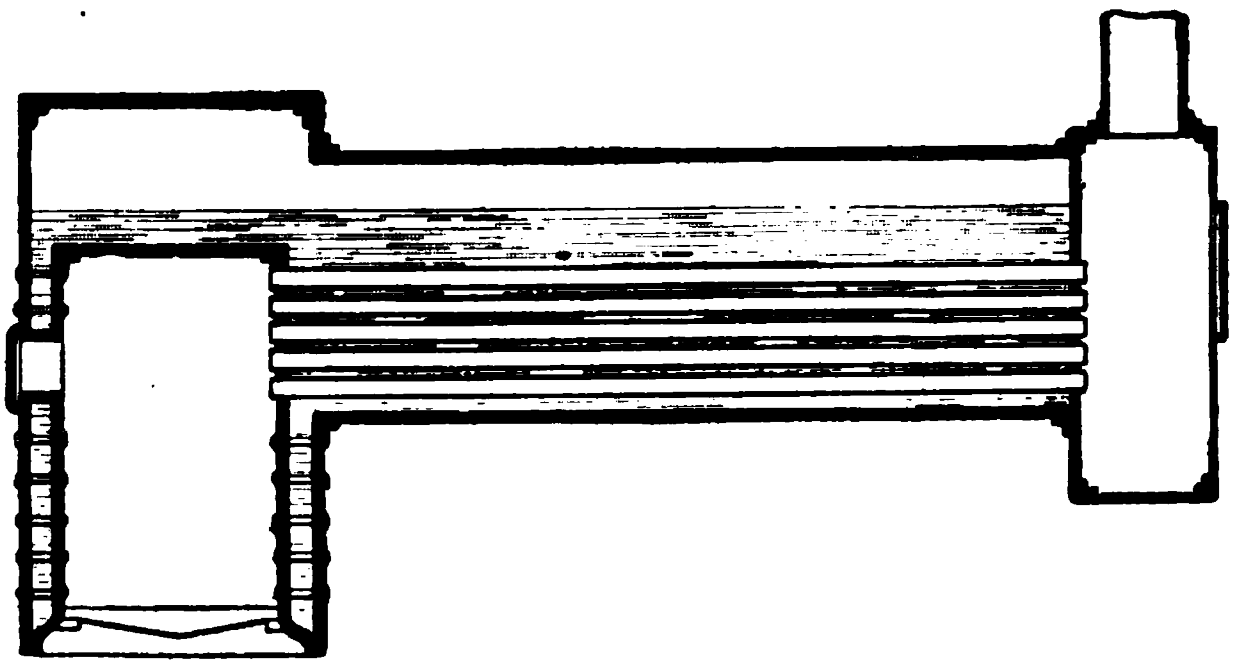


FIG. 23.

Question 78—What thickness of material should be used for the shell of a boiler if it shall act as heating surface?
Answer—The thinnest shell is one-sixth inch. This thickness may be increased according to the diameter of the boiler, its safe working-pressure, the tensile strength of the material and the kind of seam used; but, if these conditions require a greater thickness than 5-12 in., the shell can no longer be considered as heating surface, because the heat is not able to penetrate a shell of more than 5-12 in. thickness with advantage.

Question 79.—What is the difference between tubes and pipes?

Answer—Tubes must be used where the inside pressure varies from that on the outside, as when tubes are on one side under steam pressure and on the other under air pressure, and in those cases where water pressure is acting on one side of the shell, and only atmospheric air pressure on the other, the seam must be made strong and solid, and must be lapwelded.

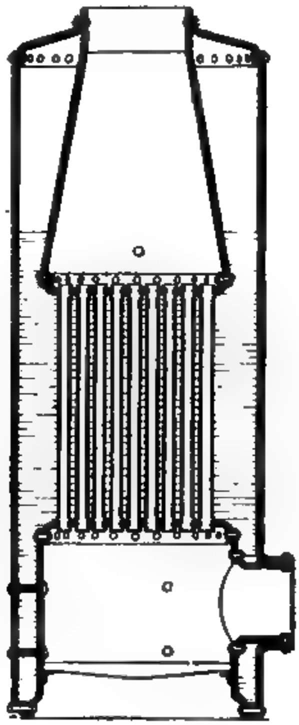


FIG. 24. FIG. 25.

In pipes, where the pressure on both sides is almost equal, as in gas pipes, we use buttwelded seams; and the diameter of these buttwelded pipes, measured by the commercial standards, will be taken at the inside of the pipe. If we mention a one-inch gas pipe, the inside diameter of this pipe is one inch, while the outside diameter is larger; but if we ask for a one-inch tube, the outside diameter is one inch, while the inside diameter is smaller.

Question 80—What do we understand by efficiency of a boiler?

Answer—The efficiency of a boiler is estimated by the number of cubic feet of cold water evaporated per hour by a certain number of square feet heating surface of the boiler.

Question 81—On what does the efficiency of a boiler depend?

Answer—The efficiency of a boiler depends on a great variety of

FIG. 26.

causes: The number of square feet of heating surface used for the evaporation of one cubic foot of water per hour varies considerably, not only in the different types of boilers, but also in one and the same type, therefore: Great attention must be paid to the thickness of shell, as well as to the conductibility of the material used; also that part of the heating surface which comes in direct contact with the flame, or that part which is affected indirectly by dark, but at the same

time heated gases. If the heating surface is only an exterior one, or if both are used at the same time, those parts of the shell receiving the heat, either directly or indirectly, will each give different effects. It must be considered that water used in boilers contains more or less impurities, causing scale, which is a poor conductor of heat. Free circulation, or impeded circulation of the water, must also be considered; the facilities for outside and inside cleaning of the boiler, the draft, also the fuel used and the attendance given to the boiler, all these are essential items, and do much to vary the efficiency of a boiler.

FIG. 27.

FIG. 28.

Question 82—In the three types of boiler construction mentioned, what is sufficient for the evaporation of one cubic foot of cold water per hour?

Answer—For a single shell boiler, 15 square feet are considered sufficient. In flue and fire-tubular boilers, the amount of square feet of heating surface needed varies between 10 and 14. In water-tubular boilers a variation of from 7½ to 13 square feet of heating surface is observed. All types governed by the conditions explained in answer to question 81.

FIG. 29.

Question 83—What do we understand by the horse power of boilers?

Answer—We really cannot express the horse power of a boiler, because water may be transferred into different kinds of steam pressures and can therefore be used as a greater or smaller power; but, we can express a commercial horse power, and we say, when a boiler is able to evaporate 10 cubic feet of water per hour, it is a 10-horse power boiler. Consequently, every cubic foot of water that the boiler is able to evaporate per hour, represents one commercial horse power; but this has nothing to do with the commercial horse power of an engine, as these expressions are in no manner equivalent.

Question 84—Is a steam-room necessary in a boiler?

Answer—Yes, and it is essential that it be made of the right size. By no means can we fill the whole boiler with water, because as soon as this is heated, it will burst the boiler. We must have therefore, a room in which the water is able to expand, and this steam-room, as has been proven by practical experiments, should be able to contain at least so much steam of three atmospheres' over-pressure as the boiler creates in three seconds' time.

Question 85—Is it allowed to use that part of the boiler shell covering the steam-room as heating surface?

Answer—If the heated gases reach the steam-room of a boiler, we may expect an accident; therefore, the water must not be allowed to come to a lower point than is reached by the supplied heat, because, as long as water lays in contact with the iron, the iron cannot receive a higher temperature than the water is able to carry under pressure while the surplus heat which is transferred to the water is used to change its aggregate. But if iron lies in contact with steam, the iron can be raised to any temperature which the heat gives out; it is able to become red, and even white hot, because steam, which cannot receive a higher aggregate, is able to stand the same heat as the iron. Now, if water is brought in contact with the red hot iron, such an amount will be evaporated at once, that the steam created, cannot be discharged from the boiler quickly enough, and so fills the steam-room with such high pressure, that the shell is not able to resist it, and an explosion is unavoidable. Therefore, it is of great importance that the water is not allowed to come below a point reached by the fire. A line drawn through this point is called the fire-line of a boiler.

FIG. 30.

Question 86—In what manner are we able to control the amount of water and the steam pressure in a boiler?

Answer—We do this by means of the boiler attachments.

Question 87—What attachments are generally used on boilers?

Answer—We use the following water-controlling attachments: 1. A water feed-pipe, also called a water supply-pipe. 2. A blow-out pipe. 3. Fusible plugs. 4. Gauge cocks. 5. A water glass. The following are needed as steam controlling attachments: 6. A steam conveying pipe. 7. A steam gauge. 8. A safety-valve.

FIG. 31.

Question 88—How must the water supply-pipe be constructed?

Answer—The pipe which shall feed the boiler must be large enough in size to allow the water which is needed in the boiler to pass without causing too much friction. It must not only allow the entry of the water into the boiler automatically, but must also stop its return, in the same manner; for this purpose a valve is used, called the check-valve. There is placed in the supply-pipe, at a point between the boiler and check-valve, a stop-cock, or globe valve; this, when closed, prevents the waste of water, while the check-valve is being reground or renewed.

Question 89—What is a valve?

Answer—A valve is an automatically-acting contrivance, which allows the passage of an æriform or liquid body in one direction, but prevents its return.

Question 90—Is a globe valve also a valve?

Answer—A globe valve is only a stopper. It has the name, valve, only on account of its shape, and because it is able to be moved to and from its seat. This is not done automatically but the globe valve is handled same as a cork or a cock, to allow required passage or to stop it. The globe valve is provided with a screw by means of which the stopper can be moved gradually.

Question 91—How is the blow-out pipe constructed?

Answer—The blow-out pipe is of larger diameter than the water feed-pipe, and must be provided with a globe valve, or stop-cock, which is kept closed, except when water shall be discharged from the boiler.

Question 92—How are the water-supply and blow-out pipes placed?

Answer—The water supply-pipe should be so arranged that the water can be discharged into the boiler at the rear part of it, near its bottom, or below the water-level. The merits of the different methods of arranging this pipe will be discussed later on. The blow-out pipe shall be placed at the rear end of the boiler into its bottom, so that the whole amount of water in the boiler can be easily discharged. Figure 32 shows such arrangement of water-feed and blow-out pipe to a boiler. In this figure, F represents the water supply-pipe; B the blow-out pipe; C represents a stop-cock, provided with a handle; V and V represent the check-valve in its casing; in the blow-out pipe *b*-1 represents the stop-cock, which can be operated only by an extra wrench. This precaution is taken to avoid accidental opening and to prevent meddling with it.

Question 93—Which is preferable in a water feed-pipe, a globe valve or a stop-cock?

Answer—The globe valve or stop-cock must both allow free passage in the water feed-pipe, and are therefore open at all times. except when closed for the purpose of regrinding or renewing the check-valve. Now, if a globe valve is used, both valve and seat are exposed to grinding matter, when muddy water is used to feed the boiler, and so we may find the globe valve to be leaking when it is closed. By the use of a stop-cock we avoid this same trouble, because the grinding matter laying in muddy water, may enlarge the passage through it, but will not injure its seat, and the cock will be found to fit per-

fectly tight when we close it. Therefore, a cock is preferable if we have to feed a boiler with water which contains solid impurities.

Question 94—What is preferable in a blow-out pipe, a globe valve or a stop-cock?

Answer—When ever the blow-out cock or the globe valve is opened to discharge water from the boiler, while same is under pressure, the force of steam is liable to drive broken-off scale through the passage with great speed and can do more injury to the stopper than when used in the water feed-

FIG. 32.

pipe; therefore, in a blow-out pipe, the stop-cock should be used under all circumstances, because its seat will not be injured like that of a globe valve. We must not only guard against the solid impurities in the water, as when scale are formed by mud, but also against the salts lying in the water in solution, which, in time, will also form a sediment and create scale.

Question 95—Why do you see more blow-out pipes supplied with globe valves than with stop cocks?

Answer—A cock easily sticks to its seat and makes it difficult for an engineer to open or close it gradually; but as it is the duty of an engineer to inspect the attachments of a boiler daily, before the boiler is put to use under pressure; this can be prevented by oiling and turning the cock once every day.

Question 96—What is a fusible plug, and for what purpose is it attached to a boiler?

Answer—A fusible plug is a hollow plug, made of brass, provided on its outside with gas-pipe thread and filled inside with pure tin, commercially called banca tin. It is inserted into the boilers from the inside of their shell to such places where the water may become low and cause the shell to get red hot. Tin is able to withstand the highest temperature of steam used in stationary boilers, but it will melt long before the shell of boiler attains a red heat. Therefore the tin will melt soon after the heating surface is uncovered by water, and before the shell can become red hot; the escape of steam will alarm the engineer and at the same time extinguish the fire

FIG. 33.

underneath the boiler, preventing an explosion. Figure 33 shows such a fusible plug; in section M, represents the mantle, provided with a head H, to be operated by a wrench, and T represents tin.

Question 97—For what purpose are gauge-cocks used on a boiler, and how are they constructed?

Answer—There are three gauge-cocks used on a boiler, and they serve for the controlling of the water-stand. One gauge-cock is placed at the basis of the steam-room, which is also the water-line; the other two are placed at equal distances above and below, this distance to be one-half of that lying between the water-level and fire-line. By fire-line is meant an imaginary line drawn horizontally through the highest point of the shell which is reached by the fire. The lowest gauge-

cock is called "first," the middle one the "second" and top one the "third" gauge-cock. They are placed obliquely to each other, so that water or steam, coming from one, cannot affect the others. These gauge-cocks must be so arranged that their passage can be easily cleaned by a knitting needle or a stiff piece of wire. In Figure 34 and Figure 35, cocks are shown so constructed, that the part S can be unscrewed for handling

FIG. 34.

FIG. 35.

the knitting needle. In Figure 36 a globe valve is used; in Figure 37 a lid valve. Construction 36 shows S as that part which must be unscrewed to use the knitting needle for cleaning. In Figure 37, on page 47, the lid valve has only to be lifted, as indicated by dotted lines, to allow cleaning of the bore by the knitting needle.

Question 98—What different types of valves have we, and how do they differ?

Answer—We have three types of valves. They are called: poppet valves, lid valves, and slide valves. The poppet valve moves vertically to and from its seat. The lid valve moves on an incline position to and from its seat, and the slide valve moves in the same plane which forms its seat.

Question 99—How must a water glass be constructed, and for what purpose is it used on a boiler?

Answer—At equal distances above and below the water-line tubes are inserted in the boiler; they are provided at their ends with sockets, into which a glass tube is set and kept tight by packing and gland. That these tubes may be easily cleaned with a knitting needle in the same way as the gauge-cocks, a screw is inserted into the socket, which can be taken out for this purpose. In each of the tubes coming out of the boiler a cock or a globe valve is placed; at the bottom of the lower socket, an extra cock is placed, called the drip-cock. This glass gauge shows at sight the water stand of the boiler.

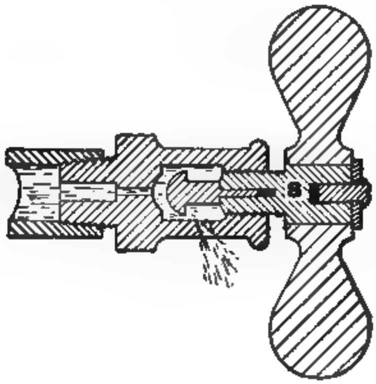


FIG. 36.

FIG 37.

Question 100—What do you understand by water column, and how is it constructed?

Answer—On account of the vibration of water by the use of steam, the sediments remaining by evaporation are able to reach and obstruct the small passages of the gauge-cocks and water glasses, which are made purposely small to avoid unnecessary waste of steam or water. To prevent their obstruction, an extra apparatus is placed in the boiler, called a *water column;* this is connected to the boiler by wider pipes

FIG. 38. FIG. 39.

and to gauge-cocks and water glass by narrower ones. The sediment settles at the bottom of this column and the smaller passages are kept free. Figure 38 shows a well constructed type of water column, in which the opening for the gauge-cocks are marked G. The water column itself is marked E, while the flanges which connect the water column to the boiler, are donated *e* and *f*; *e* is connected with the steam-room and *f* with the water-room. Sockets are screwed into this water column at the height of the flanges *e* and *f*. These sockets are open on top and bottom: The top one is marked

B, and the bottom one with C. The lower socket C is provided inside with a shoulder, so that a water glass can be inserted through the top socket B and rests on the shoulder in the socket C. Over the glass tubes are slipped the glands D and D. The top socket B can be closed by the screw *b*, and at the lower end of the bottom socket, a cock *c*, called the drip-cock, will be inserted. For cleaning the passages, both sockets are provided at *a* with screws, which can be taken out for this purpose. The glass tube is represented by the letter A.

FIG. 40. FIG. 41.

Question 101—How must the conveying pipe be constructed?

Answer—The steam conveying pipe must not only have an area which will allow the steam to pass from the boiler as fast as it is generated, but its area must be so much larger that the steam developed is able to pass through it without being hindered by friction. It must have, if the boiler is used for power purposes, an area of at least one-sixth square inch for every cubic foot of water transferred by the boiler into steam per hour; and when it is used for heating purposes, one-quarter of a square inch must be allowed for the same amount of water evaporated per hour. The steam pipe must be opened and closed gradually, and therefore a stopper, provided with a screw, as in a globe valve, must be used. The valve in the conveying pipe is called a throttle valve and is differently constructed. The Figures 39, 40, 41,

show us three different kinds of construction in sections. In Figure 39, the stuffing box of the apparatus can be packed while the valve is closed or open; on the stem of this valve, a cone *a* is fastened, which insures a tight fit against the bushing *b*, which is generally made of bronze. The valve stem is provided on its top, which reaches out of the stopping box, with a groove into which a screw C slides, which prevents the turning of the valve stem, as well as the valve on its seat. Figure 40, on page 49, shows us a steam valve which allows the steam to pass through it in a straight direction, but it can be used only in conveyng pipes of small areas, because the pressure acting against the valve makes the opening and closing of it difficult when larger areas are used, on account of the great hand-power needed. The Figure 41, on page 49, shows a valve which can be used for large areas. Here the steam passes through the valve in a straight direction, same as in Figure 40, but from the top, instead of underneath; by lifting the screw, the small auxilliary valve *a* will be opened, and so the pressure which had been resting only at the top in Figure 40, is now acting on the main valve from both sides, top as well as bottom. The main valve *b*, which moves in the cylinder, in *c*, will close the steam pipe in the direction toward the boiler; in this case the diameter of cylinder C is made much larger than the valve-seat, so that the pressure acting on top can easily be overcome by the steam pressure from beneath. When the auxiliary valve *a* is opened, the steam pressure acting underneath, assists in the lifting of the main valve, and as soon as the auxiliary valve is closed, the main valve will also be closed by the over-pressure resulting from the piston, *b* working loosely in cylinder C.

Question 102—Where must the steam conveying pipe be attached to a boiler?

Answer—The steam conveying pipe must be placed at the highest part of the steam-room of the boiler. It is quite immaterial which point is used, except in horizontal cylinder boilers, where the steam pipe must be placed at the highest part of the steam-room inside of one-third of the length of the boiler from its front. The reason for this is, that the speed of the escaping steam, forms a water spout at the level of the water and this water spout being of cone shape, the water glass would not indicate the right position of the water in the boiler; it would alternately show the glass filled with water and then empty. Figure 42 illustrates us this rising and falling of water in the water glass. The figure shows a horizontal boiler in transverse section. The line LL represents the basis of the steam room, G, a water column with glass gauge

inserted. The water room is marked W, the steam-room S, the steam conveying pipe by E. The curved lines RRI show the surface of the water when the conveying pipe

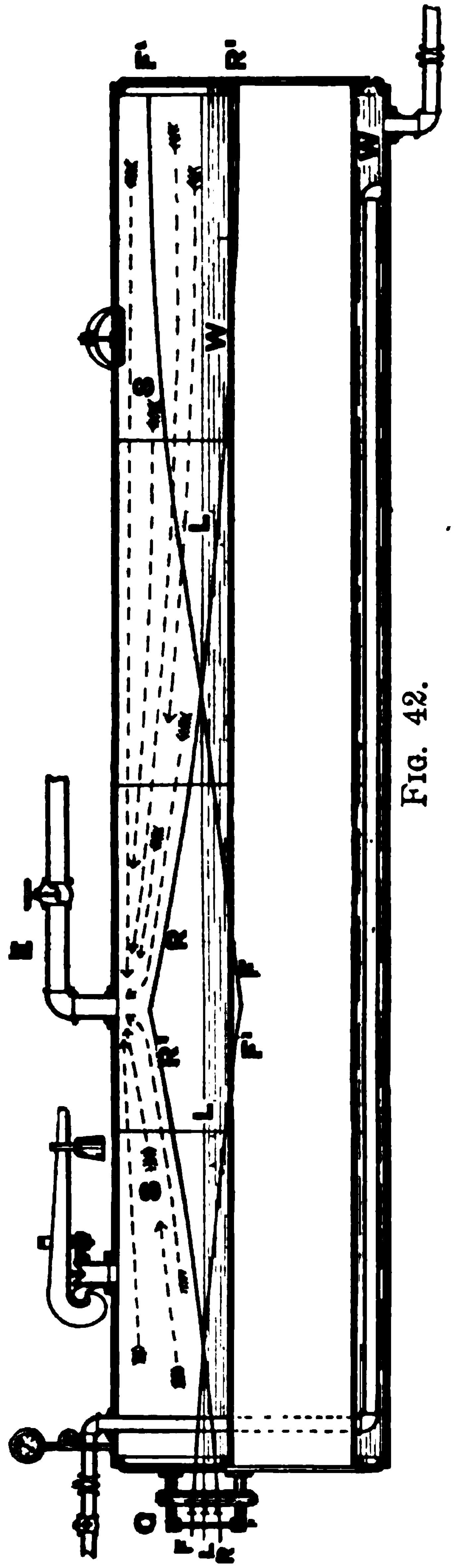


FIG. 42.

discharges steam, and the curved lines FFI show the appearance of the water when steam is not being discharged, while cut off in engine takes place. These curves show that more water is taken from the rear of the boiler than from the front; therefore the vibration of the water in the water glass does not confuse the fireman as much as if the conveying pipe were placed in the middle of the boiler.

Question 103—What is the principle of construction in a steam-gauge?

Answer—An oval pipe is used, made of spring metal, that is, thin rolled sheets, of either brass, steel or silver, which possess great resistance and can be bent, but are at the same time elastic, so they may spring back to their original shape as

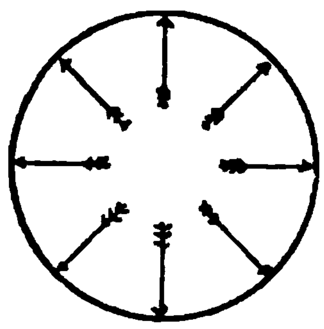


FIG. 43.

soon as the power against them ceases. Springs change their shape in the same ratio as the pressure acting upon them, and for this reason the circular-shaped pipe, as shown in Figure 43, is not used, because pressure acting in it will only change its size and not the shape. The changing of the shape of an oval pipe (Figure 44), is illustrated by Figure 43, in which a straight metallic metal strap S is supported by the two points A. As long as the pressure acts only at the points A, the shape will not change; but as soon as the pressure is moved toward the center, it will bend, and when the pressure is moved to the middle C, the strap will assume the curved shape U. The pressure in the oval pipe (Figure 44) acts mostly in the direction of the smaller radius and brings it to a more circular shape, the stronger the pressure. In the steam-gauge the oval pipe is not used in a straight shape, but

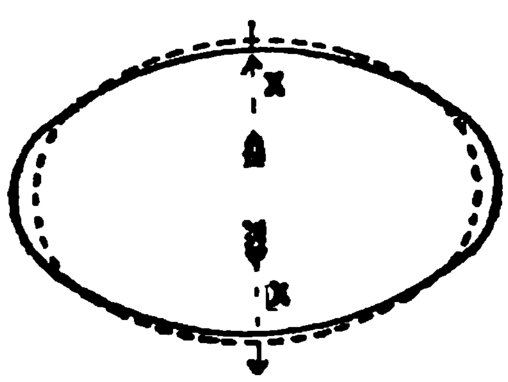


FIG. 44.

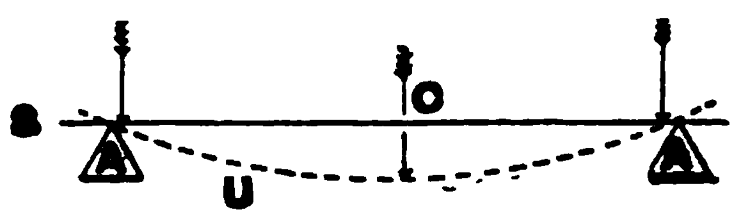


FIG. 45.

in the form of an open ring, similar to Figure 46. The greater the pressure acting in this ring, the more will the ends of it move apart, as indicated by the dotted lines in Figure 46, and if these lines are connected by lever arrangement to a cog bar or segment cog wheel, and this, in turn, is made to act against a stationary pinion (as shown in Figure 47), to which a hand is fastened, this hand will indicate on the dial (Figure 48, on page 54) the amount of pressure acting in this ring-shaped pipe.

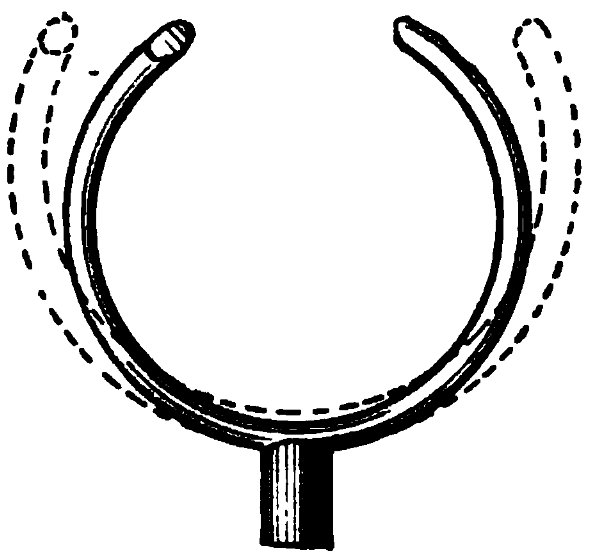


FIG. 46.

Question 104—What do you understand by a safety-valve, and how does it act?

Answer—The steam in a boiler may unexpectedly rise higher than the safe working pressure was calculated on. For this reason a contrivance is attached to the boiler, which acts automatically. This is accomplished by a covered hole in the top of the steam-room of a boiler, which is large enough to discharge steam as fast as it is generated; it will open automatically as soon as the steam pressure is higher than desired. If the safe working pressure of the boiler is, for instance, 100 lbs. per square inch, and a hole of one square inch area is large enough to allow the escape of the steam at the moment it is generated, this hole must be closed by a valve in weight of 100 lbs., or, in other words, the valve must be so loaded, that the load, together with the weight of the valve, amounts to 100 lbs.; and, if a hole of three square inches area is required to discharge the superfluous steam, the valve, with its load, must represent the weight of 300 lbs. A safety-valve should be opened every day, because it may stick to its seat through corrosion, or by being gummed up, in which case it would not act in due time, and so place the boiler in danger. It is necessary that this opening be done gradually, same as the throttle-valve in the steam conveying pipe; and since a heavy load is not easily moved by gradual means, it

is preferred to load the safety-valve indirectly. Direct loaded safety-valves will, therefore, be used only when they are concealed, so that their action cannot be tampered with. Commonly, indirect safety-valves are used.

FIG. 47.

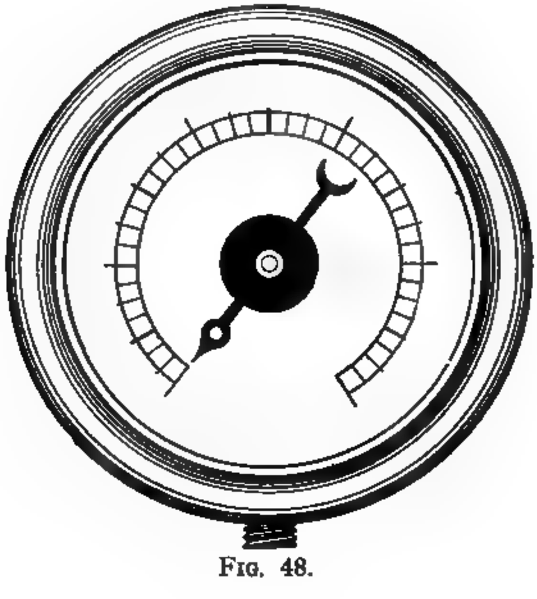


FIG. 48.

Question 105—How can we load a safety-valve indirectly?
Answer—By means of a lever.

Question 106—What do we understand by a lever?
Answer—A lever is a strong, stiff bar, which is made to swing on a point, called the fulcrum of the lever, and on this lever two powers act against each other at different points. The distances of the points on which powers are acting on the fulcrum are called arms of the lever. When the effect of the powers acting against each other on the lever balance, then the law of the lever is fulfilled. This balancing is accomplished when the power acting on one lever-arm multiplied by the length of the arm equals the power acting on the other lever-arm multiplied by the length of the latter.

Question 107—How is the lever treated in order to load a safety valve indirectly?
Answer—The valve against which the steam is acting is placed by its stem a short distance from the fulcrum, while the weight which shall counter-balance the steam pressure, is placed at a greater distance from the fulcrum.

Question 108—If the valve is placed on the short lever-arm of 3 inches length, the long lever-arm is 24 inches in length, and the counter-weight 30 lbs., what is the greatest pressure which can act against the valve without opening it, and how do you prove this?
Answer—Since the long lever-arm is eight times the length of the short lever-arm, we are able to use on the valve a pressure eight times as large as that expressed by the counter-weight. In Figure 49, the lengths of the arms are represented in inches. Whenever this lever is moved, as shown by the dotted lines, the counterweight will move through eight times

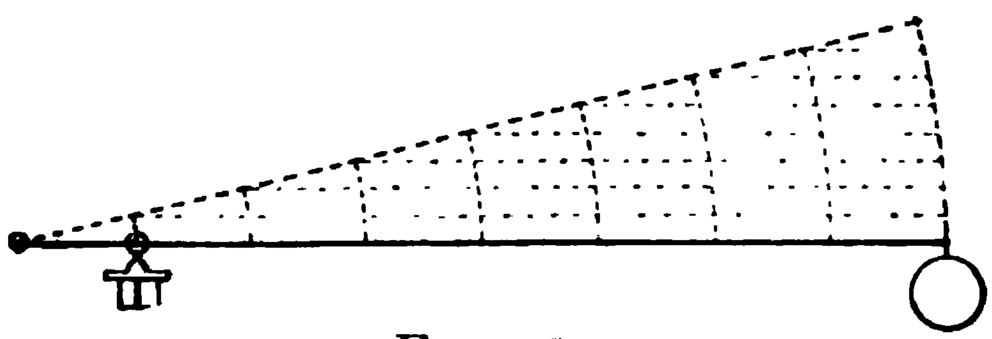


FIG. 49.

the distance of that of the valve. The work is represented by multiplying the weight by the distances through which it is moving, and these two actions shall balance each other; but as the counter-weight moves through eight distances while the valve can only move through one, and since 8 times 30 equals 1 times 240, 240 lbs. is therefore the greatest pressure which can act on the valve, without lifting it. The

action of the counter-weight is represented by multiplying the long lever-arm by the counter-weight and dividing the product by the short lever-arm:

$$24 \times 30 \div 3 = 240 \text{ lbs.}$$

Question 109—Is the counter-weight the only load acting, by means of the lever on the valve?

Answer—In addition to the counter-weight, the weight of the lever-bar and that of the valve and stem, act as a load of the valve.

Question 110—How do we determine, in the easiest manner, the action of the weight of the lever-bar, and also the action of the weight of the valve and stem on the safety-valve?

Answer—As the lever-bar is generally attached permanently at its fulcrum, and the valve is linked by the stem to the lever-bar in the same way, it is best to take the total action of these weights into consideration at one time. If a thin string is wound around that point of the lever-arm where the valve is placed, and is attached to a spring scale, and by means of this scale, the valve is lifted from its seat, the scale will indicate the pressure with which the two mentioned weights are acting against the pressure of the boiler.

Question 111—If the action of the counter-weight is added to the action of the lever, valve and stem weight, as indicated by the spring scale, we have the total action on the area of the valve; how can we find what height of pressure per square inch in the boiler can be kept in balance by this valve?

Answer—We divide the total action against the valve by the number of square inches area of the valve.

Question 112—How do we find the pressure per square inch needed in the boiler to lift the safety-valve, when it is set?

Answer—We add the actions of the counter-weight, lever-valve, and stem weight together, and divide the sum by the area of the valve.

Question 113—Having given the steam-pressure at which a valve shall be blown from its seat, how do we find the distance to set a given counter-weight on the lever from its fulcrum?

Answer—We multiply the steam-pressure by the area of the valve, subtract from this the action of the lever, valve and stem-weight, as indicated by the spring scale, multiply the remainder by the short lever-arm, and divide this product by the counter-weight.

Question 114—What counter-weight must be used, if a given steam-pressure shall not be exceeded, and this counter-weight shall be hung at a certain distance from the fulcrum?

Answer—The area of the valve is multiplied by the given steam-pressure; from this, the action of the valve, lever and stem-weight, as indicated by the spring scale, is subtracted. The remainder is multiplied by the short lever-arm, and the product divided by the distance at which the counter-weight shall be placed from the fulcrum.

Question 115—With what steam-pressure will a safety valve of 2-inch diameter blow off, when set at a distance of 2 inches from the fulcrum; the action of the weights of lever, and stem are indicated as 22 lbs. by the spring scale, and a counter-weight of 22 lbs. is placed a distance of 20 inches from the fulcrum? (See Figure 50.)

Answer—The action of the counter-weight equals:

$$20 \times 22 \div 2 = \frac{20 \times 22}{2} = 220 \text{ lbs.}$$

To this we add the indicated action of valve, lever and stem weight which is 22 lbs. which gives us the sum of 242 lbs.

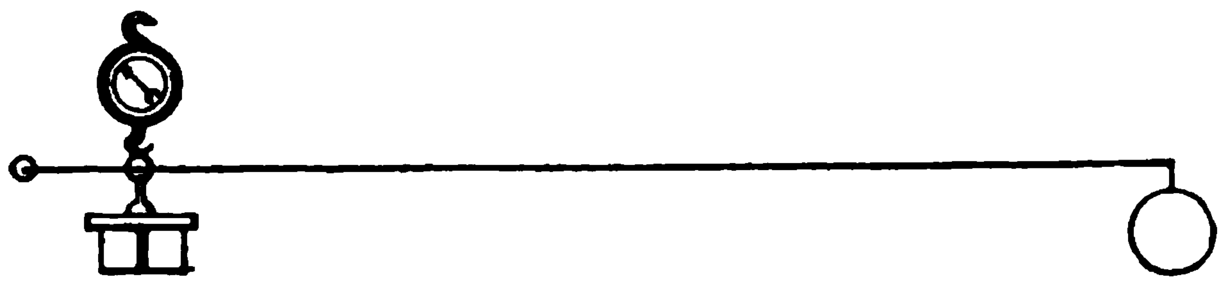


FIG. 50.

The area of the valve is equal to $2 \times 2 \times {}^{11}/_{14}$. If we divide the sum of 242 by this area, the result is:

$$\frac{242 \times 14}{2 \times 2 \times 11} = 77$$ lbs. per square inch, as the steam pressure required.

Question 116—If a safety-valve of 2-inch diameter, standing at a distance of 2 inches from the fulcrum, shall blow off by a steam pressure of 70 lbs., and the action of the lever, valve, and stem-weight is indicated by the spring scale as 22 lbs., what amount of counter-weight must be hung at a distance of 18 inches to balance the steam pressure? (See Figure 51.)

Answer—Multiply the area of the valve $2\times2\times{}^{11}/_{14}$ by the steam-pressure of 70 lbs., which is:

$$\frac{2\times2\times11\times70}{14}=220 \text{ lbs.}$$

Subtract from this the indicated action of lever, valve and stem-weight, 22 lbs., leaving a remainder of 198 lbs. This

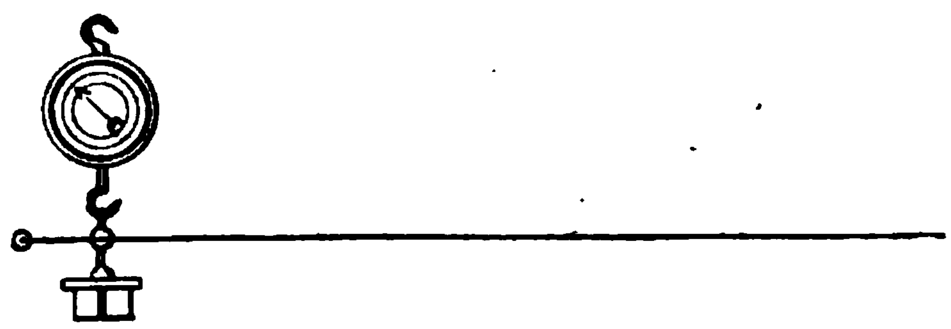


FIG. 51.

198 is multiplied by the short lever-arm, namely by 2, and this product, divided by 18, the distance between the counter-weight and fulcrum. The result is:

$$198\times2\div18=\frac{198\times2}{18}=22 \text{ lbs. for the required counter-weight.}$$

Question 117—If a safety-valve of 2-inch diameter, standing at a distance of 2 inches from the fulcrum, shall blow off by a steam pressure of 84 lbs., and the action of the lever, valve and stem weight together is indicated by the spring scale as 22 lbs., what amount of counter-weight must be hung at a distance of 18 inches to balance the steam pressure? (See Figure 52.)

Answer—Multiply the area of the valve $2\times2\times{}^{11}/_{14}$ by 84, the steam-pressure, at which the valve shall blow off, and the result is:

$$\frac{2\times2\times11\times84}{14}=264 \text{ lbs.}$$

From this subtract the indicated action of 22 lbs. and multiply the remainder of 242 lbs. by 2, the short lever-arm, and divide this by 18, the long lever-arm and result of:

$$242\times2\div22=\frac{242\times2}{18}=26.88 \text{ lbs.}$$

the distance at which the counter-weight shall be placed from the fulcrum.

Question 118—How do we decide whether water or steam is coming out of the gauge-cock?

Answer—If steam is coming out of the gauge-cock, it appears at once as fog, but if water is coming out of the gauge-cock, it leaves a small, clear space between the fog and the gauge-cock. Another method is to place a piece of dry wood a short distance from the gauge-cock; steam will not wet it, but water will.

Question 119—How must a water glass be controlled?

Answer—To control a water glass, the cock in the water pipe is closed, and the drip-cock opened. If the water remains in the glass, it is a sign that the steam pipe is obstructed, but if the water leaves the glass, it shows that the passage is open. Next, if the drip-cock is closed and the cock in the water pipe be opened, and the water reappears in the glass, it proves that the water pipe has a free passage; but if the water does not reappear, the water pipe is obstructed. If one or the other pipe is obstructed, we must clean the pipe as before explained, by using a knitting needle, or a piece of hard steel wire.

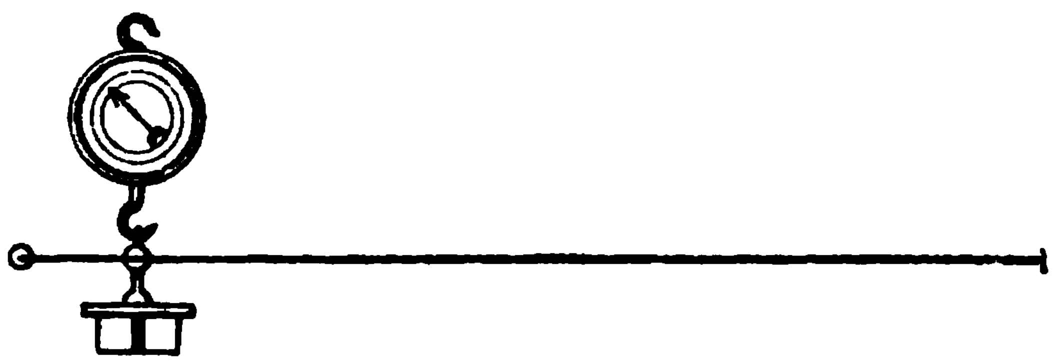


FIG. 52.

Question 120—For what purpose is a cock or globe-valve placed in the steam-pipe of a water glass, if it is not needed for the control of the water glass?

Answer—This cock in the steam pipe answers two purposes. If the glass breaks, we not only have to shut off the cock in the water pipe, but also the cock in the steam pipe; and in winter, when there is danger of the water in the glass freezing, we must drain the water glass, and to do this, we first close the water-cock, then open the drip-cock, and after the water is discharged out of the glass, we close the steam-cock.

Question 121—In case the water glass breaks, which do you close first, the water or steam-cock, and how do you proceed to insert a new glass?-

Answer—We first shut the water-cock and then the steam-cock, because the water is liable to injure one, but the steam cannot; the reason is, more units of heat are lying in water than

in steam of the same volume. To insert a new glass, first open the drip-cock, and then the steam-cock; allow the steam to blow through the glass for a while, close the drip-cock, and then open the water-cock. Should the water be permitted to enter the glass first, we may expect it to burst.

Question 122—Would you blow water out of the boiler if you see the water glass entirely filled with water?

Answer—The water glass may be filled entirely with water, and yet we may not have enough water in the boiler, because as soon as the steam pipe of the water glass becomes obstructed, the steam lying in the water glass will soon be condensed, becoming water, and the vacated space in the glass will be filled up with water by the steam pressure in the boiler; this water will remain and be kept in there by the steam pressure, even should the water go entirely out of sight at the gauge-cocks.

Question 123—How must the steam-gauge be arranged to a boiler to indicate the pressure correctly, and how do you control the steam-gauge?

Answer—To indicate correct pressure, the steam gauge must be arranged in such a manner that it stands under the influence of pressure only, and not under the influence of heat; besides, the pipe leading to the apparatus must be so arranged that it can be easily cleaned in case of obstruction. We fill our steam gauge with water and let the steam-pressure act against this water. The steam gauge attached to the boiler with a U-shaped pipe, as represented in Figure 53, or with a coil-shaped pipe, as shown by Figure 54, will allow the gauge

FIG. 53.

FIG. 54.

to be filled with water, and at the same time keep heat away from the steam gauge while steam is acting against it. To facilitate cleaning, we place in the pipe a three-way cock. Figure 55 shows this cock in such position that boiler and steam gauge are communicating, and Figure 56 shows the cock placed so, that the steam passes from the boiler to the atmospheric air, the steam driving impurities out of the pipe

FIG. 55. FIG. 56.

by its speed. A steam gauge should be cleaned often by blowing steam through it into the air. A steam gauge must also be controlled, from time to time, by the safety-valve, which is for the purpose set to blow off at a certain pressure, and if this same pressure is indicated in the steam gauge, we know that the gauge is registering correctly. A small variation in the indication of pressure does not make a gauge useless, as a fireman or engineer has only to recollect the amount of this variation.

Question 124—How must a safety-valve be controlled?

Answer—The safety-valve should be examined every morning while a low pressure is in the boiler, by lifting the lever at the greatest distance from the fulcrum slowly and gradually. It is not necessary to lift the arm more than about one-eighth of an inch. We do this for the purpose of finding out whether the valve is sticking to its seat or not. As soon as the valve is lifted, steam escapes, but stops as soon as the valve is allowed to fall back to its seat. If, however, the steam continues to escape, it shows that the valve had been stuck to its seat (by corrosion or gumming), and must be cleaned.

Question 125—Is the lever acting on the safety-valve always loaded by a weight?

Answer—The lever of the safety-valve can be loaded as well by a spring as by a weight, because the expansion or contraction of a spring shows increase or decrease of pressure in equal ratio.

Question 126—What parts are fastened to a boiler, and yet are no attachments?

Answer—Every boiler is provided with holes, which are closed when raising steam, and can be opened for the purpose of cleaning the boiler; these holes are of different sizes. A hole that is large enough for a man to enter through is called a man-hole, and a hole which will allow only the arm of a man to pass, is called a mud or hand-hole. These holes are closed by plates, called man-hole covers, and mud or hand-hole covers, and the plates are fastened so they press against the inside of the shell of the boiler. Every boiler needs such holes for cleaning. Besides these we often find on boilers a steam dome or a steam drum, and sometimes a mud-drum one or the other may be desirable on a boiler. Neither man or mud-hole covers, nor steam domes or steam drums, nor mud-drums, are called attachments to a boiler. Fire fronts and grate bars or pillow blocks really do not belong to the boiler, but to the fire place, and, therefore, cannot be called attachments.

Question 127—How is a mud or man hole cover constructed, and how is it fastened to a boiler?

Answer—The cover as well as the hole is made in oval shape, but the cover must be larger in size than the hole, and at the same time be able to slip through the hole so that it can be fastened inside against the shell. The Figure 57 shows us an arrangement for the mud-hole or man-hole cover in that part of the boiler shell which is marked in the Figure with S. The

FIG. 57.

cover is denoted with C on which a socket *c* is so arranged that the head of a bolt B can be slipped in. Between C and the shell S, a packing P is placed. A claw J is resting on the outside of the shell, so that the bolt B passes through it, and can be tightened by the nut M, in this manner pressing the cover C against the shell S, and making it steam tight by the packing P.

Question 128—To keep man or mud-hole covers steam-tight, closed against the shell of a boiler, what kind of packing must we use?

Answer—We use a great many kinds; hemp packing, paper packing, asbestos packing, leather packing, India rubber packing, and lead packing. Hemp packing is best prepared with a mixture of three-quarters of mutton tallow and one-quarter of beeswax. Bundles of hemp fibres, laying as straight as possible, should be well greased with this mixture, flattened, and placed in ring-shape on the cover, in equal thickness. By no means should hemp packing be prepared for the purpose with red or white lead and boiled linseed oil, because this will be bound tight against the shell and cover, and it will require chisel and hammer to break it away as soon as the hole shall be opened. The lead packing is preferred to all others. Some make it out of lead pipe and join the ring by a tin solder; but since tin is harder than lead, the packing may become loose at the soldered place. A leaden ring, cast in one piece, is preferable to other styles, if it is in section a square, and placed obliquely so the sharp corners rest against shell and cover, as the packing marked P in Figure 57 will show. This kind of packing can be used several times before it is necessary to recast. All the other packing materials mentioned soon lose their elasticity, are costly and their use therefore unadvisable. All packings, made in one piece, for the purpose of making two parts steam or water-tight, are generally called gaskets.

Question 129—How do the names of boilers differ in regard to the kind of fire-place used?

Answer—We have boilers, the fire-place of which is inside the boiler; the grate-bars on which the fuel shall be consumed, are laying inside of the boiler. We call this kind fire-box boilers, as shown in Figures 58, 59, 60, 61 and 62. Other boilers require extra brick work to build a fire-place; figures 63, 64, 65, 66 and 67 show such boilers, which are called bricked-up boilers or furnace boilers. In fire-box boilers, the grate-bars will be furnished by the boiler maker without extra charges, but in bricked-up boilers, an extra charge is made

for fire-front pillow and grate-bars. The fire-box boilers have only interior firing, while bricked-up boilers may have both, interior or exterior firing.

Question 130—What is the name of each of the boilers illustrated in Figures 58 to 67?

Answer—The boiler shown in Figure 58 is called a submerged upright fire-tubular fire-box boiler. Figure 59 shows an upright thorough fire-tubular fire-box boiler. Figure 60 represents a locomotive boiler. Figure 61 illustrates an upright down-return fire-tubular fire-box boiler. Figure 62 is a horizontal water-tubular fire-box boiler, with vertical standing water tubes. Figure 63 is a horizontal, bricked-up flue-boiler. Figure 64 is a horizontal, bricked-up water-tubular boiler, showing horizontally lying water tubes, connected to the main shell. Figure 65 is a bricked-up upright water-tubular boiler. Figures 66 and 67 represent a bricked-up, inclined, water-tubular boiler, known as the Heine boiler.

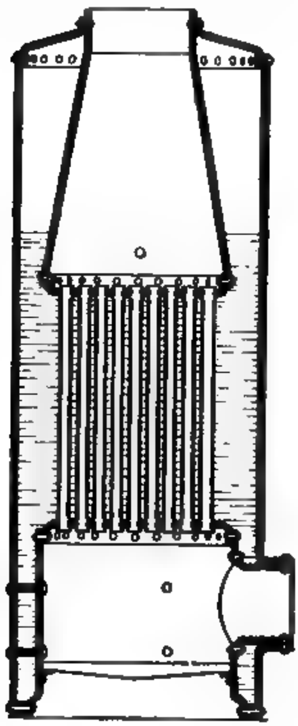


FIG. 58.

FIG. 59.

Question 131—Where do you place the gauge-cock on a horizontal flue boiler?

Answer—We place the first gauge-cock 2 inches above the fire-line, the second gauge-cock 2 inches above this, and the third one 2 inches higher. The first gauge-cock will then be 2 inches, the second 4 inches and the third 6 inches above the fire-line.

Question 132—Where do we place the gauge-cocks on a horizontal fire-tubular boiler?

Answer—The gauge-cocks must be placed at least 3 inches apart from each other, and the first one at least 3 inches above the fire-line.

Question 133—Where would you place the gauge-cocks on a locomotive boiler?

Answer—The highest point reached by the fire in a locomotive boiler, lies in the plate which is placed above the fire-box; this plate is called the crown-sheet of the boiler. The first gauge-cock will be placed at least 3 inches above the highest point of the crown-sheet (this point will be called the crown of the boiler), and the distance between each two gauge-cocks must also be at least 3 inches, because a locomotive boiler is considered as a horizontal fire-tubular boiler.

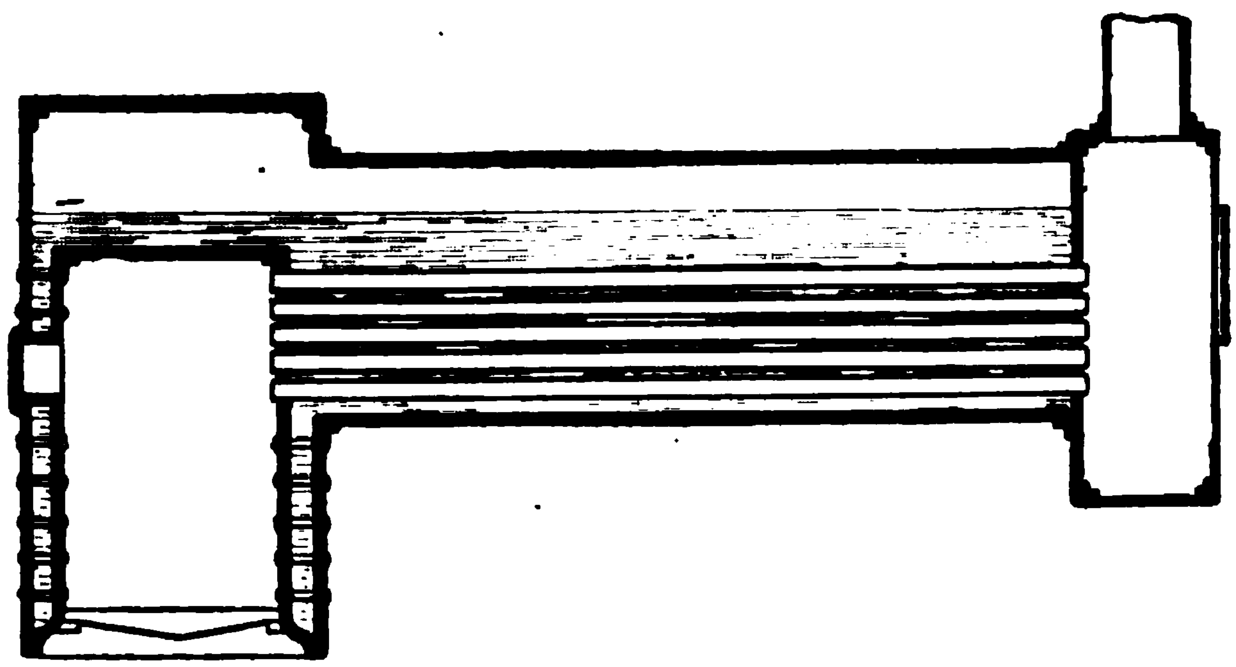


FIG. 60.

Question 134—Where do we place the gauge-cocks on an upright, down-turned fire-tubular boiler?

Answer—In this kind of boiler the highest point of the plate on top of the fire-box represents the highest point where the fire is able to touch the boiler; this plate will consequently be called the crown-sheet of the boiler. In this kind of boiler we place the first gauge-cock at least 3 inches above the highest point of the crown-sheet, and the distance between each two gauge-cocks must also be at least 3 inches.

Question 135—Where do you place the gauge-cocks on an upright, submerged fire-tubular boiler, and where on an upright, thorough, fire-tubular boiler?

Answer—The plate at the top of the fire-box in both these boilers does not represent the highest point which the fire is able to reach and we really have no distinct fire-line in these two boilers by which we are able to decide the position of the gauge-cocks. On all boilers which do not show a distinct fire-line, the position of the gauge-cocks must be decided by the basis of the required steam room; this point represents the position of the water-line and here the second gauge-cock is placed. The distance between the first and second gauge-cock must be so arranged that the water lying between the two cocks cannot be evaporated within 15 minutes, and the third gauge-cock is placed so much above the second gauge-cock, as the first stands beneath it.

FIG. 61.

Question 136—Where do you place the gauge-cocks on water-tubular boilers?

Answer—On water-tubular boilers there is also no distinct fire-line, and the second gauge-cock must be placed at the basis of the steam-room. The first and third are placed apart in distances from the second, according to the rule given in answer to preceding question.

FIG. 62.

Question 137—What is the largest size of fusible plug used, and where is it set on the boiler?

Answer—Fusible plugs shall be used which are of an external diameter of not less than one-inch gas-pipe, screw tap, and with internal opening of not less than one-half inch at their smallest, and should be inserted from the inner side of the boiler into the crown-sheet of fire-box boilers at its highest point, and into the main shell of horizontal bricked-up flue or fire-tubular boilers at a distance of one inch above their fire-line, reaching into the fire-place near the bridge-wall.

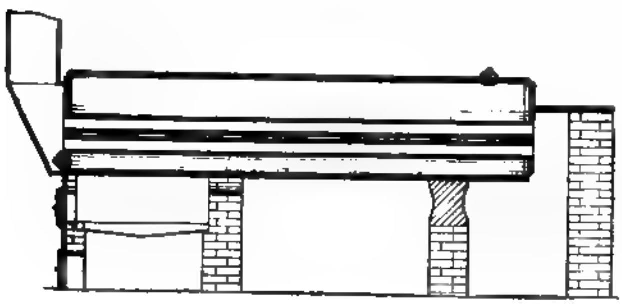


FIG. 63.

Question 138—What smaller sizes of fusible plugs are made, and where are they set on a boiler?

Answer—A fusible plug whch is made of an external diameter, equal to that of a three-fourths inch gas-pipe screw tap, with an internal opening of one-half inch, must be inserted in bricked-up horizontal flue boilers in one flue of the top row, not more than three feet from the rear of the boiler, provided that the flues are seven or more inches in diameter. In a bricked-up, horizontal, fire-tubular boiler, a fusible plug must be inserted in one of the tubes of the top row, to be of an outside diameter equal to that of a three-eighths inch gas-pipe screw tap, with an internal opening of one-fourth of an inch, not more than three feet from the rear of the boiler.

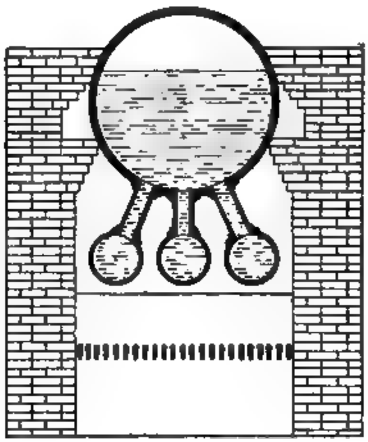


FIG. 64.

FIG. 65.

Question 139—Why does the position of the steam conveying pipe on horizontal flue or fire-tubular boiler, when placed inside of one-third of the length of the boiler towards its front, affect the position of the boiler itself?

Answer—The boiler must be placed in an inclined position towards the rear to the amount of one inch for every ten feet of its length, to prevent the rear part of the top row of flues or fire-tubes becoming uncovered by water, as long as steam is taken from the boiler, because at such times more water is taken from the rear than from the front.

Question 140—Why is a fusible plug in a horizontal, bricked-up, flue or fire-tubular boiler placed in a flue or fire-tube at its rear end, where the water itself stands, higher than in front?

Answer—The water stand may be easily observed by the water glass, but not at the rear end of the boiler, and, since more water is taken away from the rear than from the front as soon as steam is taken from the boiler, it is advisable to place the fusible plug as near the end as possible.

FIG. 66.

Question 141—A fusible plug in the rear of a boiler of 35 feet in length is set about 3 inches lower than the front fire-line: now, why is it that the fusible plug in the front of a boiler is placed in the shell one inch above the fire-line?

Answer—The shell inside of the fire-place nearest to the bridge-wall is very liable to become red hot above the fire-line, because at this place the fire develops the greatest heat, and is bound to make the fire-tiles, which meet the fire-line with their lower side, white hot to a thickness of one inch. If the water would come at this point, that it would lay only one inch above the fire-line, the shell would receive the heat from the white hot fire-tile, and an accident could only be prevented by a fusing plug placed one inch above the fire-line.

Question 142—What other attachments, in addition to the before mentioned eight, do we sometimes find on boilers?

Answer—As such attachments for the control of water and steam, may be named the safety-plug, floaters of various construction, and the steam whistle.

Question 143—What is a safety-plug?

Answer—Its object is similar to that of the safety-valve, and one of the best constructions is illustrated in Figure 68. It is

FIG. 67.

filled with an alloy, and the mixture of different metals for different steam pressures is shown in the following table:

Portion of Weight			The Alloy Melts at	
Bismuth.	Lead.	Tin.	Celsius.	Atm. Pressure.
5.	[illegible]	2.	91.50	.75
8.	3.	3.	94.25	
8.	6.	3.	97.25	
8.	5.	3.	100.00	1.00
8.	8.	3.	107.75	1.25
8.	8.	4.	113.30	1.50
8.	8.	6.	117.50	1.75
5.	1.	4.	118.90	
8.	8.	[illegible]	123.30	2.00
8.	10.	[illegible]	130.00	2.50
8.	12.	8.	132.40	2.75
1.	....	1.	141.20	3.50
8.	16.	[illegible]	142.30	3.75
8.	16.	12.	[illegible]	4.00
8.	[illegible]	24.	153.80	5.00
8.	[illegible]	36.	160.20	6.00
8.	32.	[illegible]	166.50	7.00
8.	30.	24.	172.00	[illegible]
1.	...	[illegible]	200.00	15.00

The Figure 68 shows a short pipe extending out of the highest part of the steam-room of the boiler; this pipe must be of sufficient area to allow the steam to escape in the same

FIG. 68.

FIG. 69.

time that it takes the boiler to generate it. On this pipe is screwed a ring-shaped arrangement R, having inside a shoulder on which the cup C is ground air-tight. The ring R is closed by screw D, in which another screw B is inserted. If in the cup C a quantity of alloy is melted, and allowed to become solid again, the screw B will hold

FIG. 70.

the cup C by means of this alloy A perfectly tight on the shoulder of the ring R. But as soon as the safe working pressure, according to which the alloy was selected, is exceeded, the alloy melts, the steam-pressure lifts the cup C, and the steam is able to escape through the perforations C in the ring R. These perforations correspond in sum with the opening left between the shoulder of the ring R and the

cup C. The alloy A, as soon as the steam pressure is moderated, becomes solid, and the apparatus needs no renewing of alloy.

Question 144—What do we understand by a floater, used as an attachment on a boiler?

Answer—Floaters are often used to ascertain the height of the water in the boiler, and when carefully handled, they will indicate correctly. Generally, hollow globes, made of sheet copper, are used for the purpose; but as the steam-pressure may collapse such hollow globes, it is advisable to place a few drops of water into them before they are soldered together,

FIG. 71.

because the water in the boiler and the steam in the globe will always remain at the same pressure as the steam in the boiler. The only difficulty with floaters is to make the opening in the boiler for the shaft which transfers the motion of the floater to the indicator outside, absolutely steam-tight, and yet allow a free, easy motion to the shaft. The motion is usually transferred by means of a smooth, stiff wire to the outside, passing through a stuffing-box; this stuffing-box must be filled only with the finest cotton wick, and the best and thinnest lubricat-

ing oil should be used, and the stuffing-box should never be packed too tight. The undulation of the water in the boiler makes it advisable to arrange the hollow ball so that it can oscillate; this form of floater, represented in Figures 69 and 70, is much in use. In these figures A represents the bearing and stuffing-box of the oscillating ball C; A is fastened to the shell S in a horizontal position, and the hand B on the outside shows the height of water in the boilers. The best floater in use is the magnetic floater; it is arranged by fastening a rod vertically to the floater, and to the upper part of this rod a strong magnet is attached, which is guided in a closed brass pipe screwed into the boiler. On the outside of this pipe a small iron roller follows the motion of the magnet and so indicates height of water in the boiler.

Question 145—How is the steam whistle constructed?

Answer—Figure 71 represents a section of a steam whistle. E is the housing of a cock A, which is provided with a wooden handle B. The top part of this housing enlarges, and through the holes CC the steam escapes when the cock is opened. The housing over CC is almost closed by plate F. This leaves between the mantle of the housing E and itself only a very small ring-shaped opening, and over this hangs a cup D, which on its under side, is turned off to a sharp edge. As soon as the steam escapes in the direction of the arrows and strikes this sharp edge, it sets the cup D in vibration and so causes the shrill, penetrating sound of the whistle.

Question 146—To what height will a valve, when balanced, be raised automatically from the seat?

Answer—The height to which a valve is lifted from its seat is estimated as one-eighth of its radius.

Question 147—What is the ratio of the area which is lying between the valve and its seat to the area of the valve itself, when the diameter of valve, for instance, is two inches?

Answer—The area of the opening which shall be closed by the valve is four times as large as the area of the opening which can be made between valve and seat: if the diameter of the valve is two inches, its area is, $2\times2\times{}^{11}/_{14}=3^{1}/_{7}$ square inches. Now, the circumference of a circle of two inches diameter is:

$$\frac{2\times22}{7}=6^{2}/_{7}\text{ inches,}$$

and if we multiply this, the height to which valve can be raised, namely, the eighth part of the radius which is one inch, we receive

$$6^2/_7 \times \frac{1}{8} = \frac{44 \times 1}{7 \times 8} = \frac{11}{14}.$$

is the fourth part of $3^1/_7$, we must make the opening in the seat of the safety-valve four times as large as the opening between valve and seat, through which the superfluous steam can escape into the atmosphere.

Question 148—What is understood by the speed of a body?

Answer—By the speed of a body is understood the distance, expressed in feet, through which a body is passing in one second's time.

Question 149—What speed has steam of different pressures?

Answer—By practical trials it has been found, that steam of different pressures varies in speed as follows:

Steam of 1¼ atm. has a speed of 590 feet per second.
Steam of 1½ atm. has a speed of 820 feet per second.
Steam of 1¾ atm. has a speed of 984 feet per second.
Steam of 2 atm. has a speed of 1115 feet per second.
Steam of 2½ atm. has a speed of 1213 feet per second.
Steam of 3 atm. has a speed of 1312 feet per second.
Steam of 3½ atm. has a speed of 1377 feet per second.
Steam of 4 atm. has a speed of 1429 feet per second.

Question 150—Is steam of a high pressure able to leave a boiler as fast as that of a low pressure, both passing through the same size of opening?

Answer—Steam of high pressure will leave the boiler in a given time in greater volume than steam of low pressure. This proves that a boiler in which a high pressure is used, needs a smaller opening for the safety valve, than a boiler used for low pressure, when the same amount of water is evaporated per hour in both boilers.

Question 151—What must be the diameter of a safety valve of a boiler used for heating purposes, and what shall it be when used for power purposes, both boilers evaporating 20 cubic feet of water per hour?

Answer—In a low pressure boiler, which means a boiler used for heating purposes, the steam need not be of more than 1½ atmospheres real pressure or ½ atmospheres overpressure, and therefore the speed of this steam will be calculated at 820 feet per second. But in a high pressure boiler, which means a boiler used for power purposes, the lowest pressure will be

4 atmospheres, real or 3 atmospheres over pressure, and the speed of this steam is calculated at 1429 feet per second. The diameter of a safety valve being expressed in inches, the speed per second must be reduced to inches and the amount of steam produced per second must also be expressed in inches. The calculation for the low pressure boiler will therefore be made as follows:

20×1728	×1168,508		×4	×14	=5,8037
60× 60		×12× 820		×11	
cubic inches of water used per second, - -					
cubic inches of steam produced per second, - -					
square inch opening needed between valve and its seat, - - - - - - - - - .					
area needed in opening of the valve-seat, - - - -					
square erected on the diameter of this hold, - - - - - - -					

The square root of the figure 5,8037 gives the diameter of the safety valve for low pressure boiler in length inches.

$$\sqrt{5,8037}=2.41 \text{ inches.}$$

The safety valve on the boiler for power purpose requires the following calculation:

20×1728	×475,358		×4	×14	=1.3547
60× 60		×12×1429		×11	
cubic inches of water used per second, - -					
cubic inches of steam produced per second, - - -					
square inch opening needed between valve and its seat, - - - - - - - - - - -					
area needed in opening of the valve-seat, - - - -					
square erected on the diameter of this opening, - - - - -					

The square root of the figure 1.3547 gives the diameter of the safety valve for the high pressure boiler in length inches:

$$\sqrt{1.3547}=1.17 \text{ inches.}$$

Question 152—What must be observed in the construction of a safety valve which is loaded indirectly by weight?

Answer—The composition of the metal used for valve and seat must be very hard. It is recommended that the point at which the action of the load will be transferred to the valve lies lower than the seat of the valve. The Figure 72 shows a valve so constructed. The steam escaping through a valve of this construction cannot tip the valve, neither can a strong pressure be brought against the guides of the valve, though they lay below the valve, they may be even given a little play, because the valve is always in equilibrium.

FIG. 73.

Question 153—What has to be observed in the construction of a valve which is loaded indirectly by a spring?

Answer—The material used should be the same as described in answer to the previous question. Spring weights are inferior to actual weighting in this respect, that at each lifting of the valve the represented weight on it increases, because of the tension on the spring. On this account the steam, already at the highest desired pressure, and ready to escape, is hindered in its flow. This trouble is overcome by using the construction represented in Figures 73 and 74.

Figure 73, on page 77, shows the position when valve is closed, and Figure 74 while open. The valve acting at the lever at 0, is loaded by this lever, which has its fulcrum at N; on this lever a spring is acting, enclosed in a cylindrical housing, and its action can be regulated at C. The method of joining the spring to the valve lever has the effect to make the strain on the two almost equal, no matter what the position of the lever may be. For this purpose a bell crank, B, A, D, is used, whose fulcrum is at A. A spring is connected to the lever arm AB, and to the arm, AD, a connecting rod is adjusted which shall act with a constant power on the valve lever. It is a well known fact that on a bell crank, when in motion, the ratio of power to load is constantly changing, provided the direction of these two powers remains the same. This peculiar quality is put to use here, so that the ratio of transfer between spring power and valve lever is almost in reverse to the spring tension.

FIG. 74.

Question 154—For what purpose is a dome used on a boiler?

Answer—There may be sufficient steam room in the boiler, but if the water level is too near the steam conveying pipe, water will be easily taken along with the conveyed steam, and surcharged or wet steam is brought into the apparatus where dry

steam is needed; no power can be obtained from such steam, on the contrary, it may damage the apparatus in which it is used, because impurities can be taken along. In such a case the conveying pipe must be brought at a greater distance from the water level, by placing a dome on top of the boiler. When water is taken from the boiler along with the steam, we say the boiler is priming.

Question 155—In what other way can priming of the boiler be prevented than by the use of a steam dome?

Answer—This may be done by baffle plates or by baffling tubes. Figure 75 shows a baffle plate, and the arrows mark the roundabout course through which the steam is carried, so as to allow the water to drop before it can enter the conveying pipe. Figure 76 shows us the second method. In this case the steam conveying pipe B, reaches over half way into the

FIG. 75.

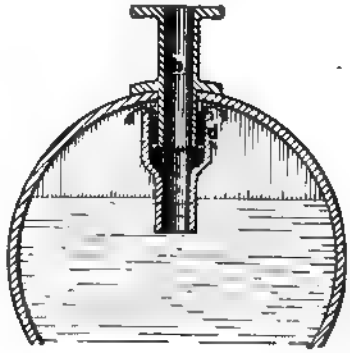


FIG. 76.

boiler to the water level and is inserted into and encircled by another pipe E, which reaches nearly to the top of the boiler, and about three inches into the water. The encircling pipe D is fastened to the conveying pipe B so that the free passage of steam between the pipes D and B is possible. The arrows in this figure show the circulation, and the steam, by its up and down motion through the pipes, is able to lose the water easily on account of the long distance it is made to travel.

Question 156—Under what circumstances must a steam drum be added to a boiler?

Answer—If the steam-room in the main shell is made too small, the steam is used up quicker than it can be produced. The steam-pressure is consequently reduced; and while the water,

especially in its top layer, retains a higher temperature, the boiler is bound to foam. When this happens there is a danger of losing a great amount of water out of the boiler, and the uncovered heating surface would receive the heat, become red hot and cause an accident. To prevent this, the steam-room must be enlarged, and this can only be done by the addition of a steam drum to the boiler.

Question 157—What is understood by foaming of a boiler?

Answer—When the water in a boiler is standing under pressure, the ebullition of the water stops, but if a sudden decrease of pressure takes place, the water commences to make violent ebullitions. Every particle of water that carries a higher temperature than the steam, transfers at once its surplus of sensible into latent heat and the water is evaporated so in the whole bulk. The water is mingled with the steam, and fills up the whole boiler-room with a foam; this will be taken with the steam to the apparatus in which it shall be used, and while the water leaves the boiler, it places not only the boiler in danger, but also the apparatus in which the steam is used, since impurities are taken along.

FIG. 77.

FIG. 78.

Question 158—Is it only the sudden decrease of the pressure resting on the water which causes it to foam; is it not also caused by dirty or greasy water?

Answer—It is quite immaterial what kind of water is used, distilled, muddy or greasy water. As soon as the pressure resting upon it is suddenly decreased, it will foam. For experiment, we partly fill a bottle with either kind of water mentioned and bring it to the boiling point, cork the bottle and take it away from the fire, ebullition will stop immediately. If we then cool off the steam-room, the water (it may be distilled, muddy or greasy), will commence to make ebullitions at once, and this is called foaming. The ebullitions in muddy water are more violent than in distilled water, and in greasy water still more so, as may be observed while water is boiling. Mud or grease is consequently no cause for the foaming of water; it will only affect the degree of foaming.

Question 159—How are tubes connected to the main shell?

Answer—The Figures 77 and 78 show the different methods of joining tubes to the boiler shell. Figure 77 shows a straight hole bored through the shell, the exact size of diameter of tube. A tube expander is applied to the tube to form a shoulder on the inner side of the boiler sheet, while the end of the tube is turned over to the outer side of the boiler sheet. In Figure 78 a slightly tapered hole is bored through the shell, the tube inserted into this hole, and a ferrule driven in to expand it.

Question 160—What must be the height of a fire-box in a fire-box boiler, when soft coal is used as fuel?

Answer—The distance between the grate-bars and the top of the fire-box shall be 24 inches.

Question 161—What dimensions must be considered when bricking-up a boiler?

Answer—The fire-place or boiler furnace must have, when soft coal is used as fuel, a distance of at least 19 inches between the grate bars and the lower part of the boiler. The side walls of a boiler shall be at a distance of at least 4 inches from the boiler. The rear wall must be set away from the boiler at least 13 inches. The length of the grate bars should never be more than 6 feet; 5 feet is really all that a fireman is able to control on furnaces with ordinary draft. One who is not skillful enough, is hardly able to control a grate surface of more than 4 feet depth. The distance between the fire-front and bridge-wall is important only so far, that the depth must be greater when the firing is attended to at long intervals; but if this can be done often, the grate surface need

not be so large. The pillow is placed at a distance from the rear equal to one-fourth the length of the boiler. The space between bridge-wall and boiler must be in area equal to the sum of the areas of the flues or fire-tubes, channels and other passages for heated gases. The area of the smallest opening in the chimney must be five-fourths of the sum of areas of flues or fire-tubes, channels, etc.

Question 162—Why is the fire-box on a fire-box boiler made higher than the fire-place of a bricked-up cylindrical boiler?

Answer—While the cylindrical-shaped boilers in horizontal position are most always used when bricked up, the distance between grate bars and the bottom of the boiler was given at 19 inches, because the fire reaches higher than the bottom of the boiler, it surrounds more than half of the cylinder, and gives on the side of the boiler ample space for the flame to develope to the same extent as in the fire-box boiler.

Question 163—Why is it not allowed to bring the sidewalls at a nearer distance than 4 inches to the boiler?

Answer—The sides of the boiler which are exposed to fire or heated gases, must be inspected and cleaned from time to time, like the balance of the heating surface. When making this inspection, it is necessary for the person doing so, to place the top of his head against the side wall, and in this position the line of vision can not reach if the space were made smaller.

Question 164—What is the reason that the rear wall must be placed at a distance of 18 inches from the boiler?

Answer—If the distance were smaller, it would not be possible to enter the bricked-up space, which is needed not only for cleaning and inspecting of the main shell, but also for the inspection and cleaning of the flues and fire-tubes. The space of 18 inches is necessary for a man to turn around in.

Question 165—Why must the space between bridge-wall and boiler be of an area equal to the sum of areas of flues, etc?

Answer—If the space were larger, the draft would be obstructed by the flues or other passage, and if it were made smaller, the heated gases occupying the room in the passage would expand, and a smaller amount of heat brought in contact with the shell than is possible.

Question 166—Why must the area of a chimney at its smallest opening, be 25 per cent larger than the sum of the area of the flues, etc.?

Answer—If the area of the chimney were made smaller than required, the friction of the gases on their passage from the grate surface to the top of the chimney, would diminish the

draft, and also the combustion of the fuel, and as the proper amount of heat could not be applied to the water, the boiler would not reach its full efficiency.

Question 167—If the sum of the area of the flues is 120 square inches, how large must the area of the chimney be?

Answer—Multiply the sum of the areas of the flues, consequently $120 \times 5/4$, and the result is $120 \times 5/4 = 150$ square inches.

Question 168—If the area of the chimney is 150 square inches, how large can the sum of the areas of the passages for heating gases be that are to connect with this chimney?

Answer—Multiply the area of the chimney by 4/5, and the result in this case will be $150 \times 4/5 = 120$ square inches.

Question 169—If the area of the chimney shall be 144 square inches, and it is intended to erect a square chimney, what must be the side of the square?

Answer—The square root of the given area shows the side of the chimney: $\sqrt{144} = 12$ inches.

Question 170—If it is intended to erect a round chimney, the area of which shall be 154 square inches, how is the diameter found?

Answer—Divide the given area by 11/14, and extract from the quotient the square root $154 \div 11/14 = 121$, and the root of this is: $\sqrt{121} = 11$ inches.

Question 171—How high must the chimney be for a boiler furnace?

Answer—A height of about 35 feet is sufficient to create a natural draft.

Question 172—Would a chimney draw better if it were higher than 35 feet, and would it draw twice as well if it were 70 feet in height?

Answer—If the height of a chimney is increased, it also increases the draft, but not in the same proportion as the added height, on account of the different influences that can retard the draft. The greater the conductibility of the material used for the chimney, the rougher the surface, the longer the passage through which the heated gases must travel—all these will have the effect of retarding the draft. If the height were made ten times as great, it would not increase the draft ten times, but hardly two. The surest way to improve the draft is to increase the area of the chimney.

Question 173—How must a boiler be started for use?

Answer—The boiler, as well as the passage for heated gases, should be clean, the furnace in good order, consequently the grate-bars in the right position, the grate surface clean, as

well as the ash pit. The attachments of the boiler should be in good order, consequently well inspected, and a sufficient amount of water must be in the boiler. Then the fireman may attend to the fire, and raise it gradually until steam of the right pressure is obtained.

Question 174—What is understood by "the boiler must have sufficient water before it is started?"

Answer—The water becomes heated; it expands and increases its volume, and when using water at zero degrees in a boiler every ten gallons of this cold water is transformed into about ten and one-half gallons of boiling water; consequently it is well enough to start the boiler if the water shows only to the first gauge-cock. The water, after it is heated, occupies a larger room, and as soon as steam is raised, it is an easy matter to fill the boiler up to the second gauge-cock. Should the boiler, at the start, be filled with cold water up to the second gauge-cock, the third gauge-cock may show water when steam is raised; it would then be necessary to blow out the surplus of the water, resulting in a loss of heat and a corresponding loss of fuel.

Question 175—How is the fire started in a boiler furnace, or in a fire-box boiler?

Answer—A good layer of shavings and kindling wood is placed on the grate surface, and a light layer of coal to the height of about two inches may be placed on top of it. The shavings are then kindled, and the fire door closed. If the fire door is opened after a little while, different results may be expected. The fire may burn first rate; or it may be that the fire is extinguished, without having consumed the kindling; or there may be no fire in the furnace, but an abundance of smoke pouring out.

Question 176—If the fire does not burn, and the furnace is filled with smoke, what is the cause?

Answer—This is a sign that the chimney does not draw well. It will happen after the boiler has been at rest for some time, or after a wet or cold period; under these circumstances a fire should be started in the chimney, with kindling wood, and as soon as the air in the chimney is warmed up, it will be found easy to start the fire in the furnace.

Question 177—If, on opening the fire door, no smoke is observed, we find that the wood has not been consumed, nor the coal ignited, what is then the cause?

Answer—The chimney has too much draft. It would be well to place first a light layer of coal on the grate surface, then the shavings and kindling, and a small layer of coal covering

this. If the shavings are now lighted, and the fire-door left open for a little while, until the wood is all burning, then the fire-door may be closed and in a short time the fire will be ready to receive another layer of coal.

Question 178—How high do we place the fuel on the grate surface?

Answer—We should never have the soft coal lying lower than three inches, and not higher that seven inches; because if lower, the draft is able to extinguish the fire, and if higher, a sufficient amount of air cannot be brought in contact with the fuel, in order to develop the heat required.

Question 179—What size of soft coal should be used for firing?

Answer—Soft coal should be broken up about the size of a man's fist. If smaller pieces are used the draft will be obstructed, and if larger, the air cannot be brought sufficiently in contact with the fuel to properly combust it.

Question 180—Which is better, to fire at short intervals with light layers of coal, or at long intervals with heavy layers?

Answer—The fire door should not remain open for too great a length of time, because the air passing over the fire will not aid, but hinder the combustion and cool off the boiler. When firing frequently, the total length of time that the fire door remains open need not be greater than if a large amount of fuel is fed at once. But it is advisable to fire often instead of at great intervals, because a heavy layer of coal on the fire at once will take a good while to kindle, and during this time the proper amount of heat cannot be supplied to the boiler, as it is cooling down, and an incomplete combustion takes place, the combustible gases escaping unused through the chimney.

Question 181—How must the fire be attended to?

Answer—The coal should lay at equal height all over the grate surface. Open spaces are not allowable, because cold air would pass through those spaces without aiding the combustion and be discharged through the chimney, which is there only for the purpose of discharging the result of the combustion, and so the draft would be handicapped. Whenever the layer is too light, or has open spaces, the cold air is able to extinguish the fire. If too heavy a layer is placed on the grate surface, or slack coal is used, a sufficient amount of air is not able to come in contact with the fuel, and the combustion is incomplete. A gas will be discharged through the chimney which is combustible, but it will not kindle except it is exposed to a temperature of 400 degrees, and in this way half of the heat which we are able to develop from the coal is lost.

• The fire should never be poked. When it is not active enough, use a hook underneath the grate surface, to clean the spaces between the grate bars of ashes. A poker is used only when clinkers lie in the fire on the grate surface; but even then the poker should not be used in an inclined position towards the grate surface. After the fireman has ascertained the position of these clinkers on the grate surface by the hook, he shall use the poker, resting its whole length as far as it is able to reach the grate surface, using the fire door frame as a fulcrum, his poker as a lever, and loosen the clinkers from the grate surface; they will fly up to the top of the layer of coal and must be brought towards the front of the boiler, near the fire door, and be taken out at the first opportunity. The fireman should never feed fuel while the steam in the boiler is going down; he should brighten the fire by using the hook, and as soon as the steam is raising, he can throw in fuel, after this it will take some time for the fuel to kindle, and during this time the steam will again go down. When the fireman has started a fire, he should never try to hurry it. He must recollect that a boiler has more or less scale resting on its shell, which is a very bad conductor of heat, and the shell on which such scale rests may become red hot before the heat is able to penetrate the scale. The fireman should, therefore, fire up very gradually, to give the scale time to receive the results in high temperature, and he should also recollect that to raise the pressure in a boiler to the required height before steam is needed results in an unnecessary loss of steam by blowing off through the safety-valve.

Question 182—When must water be supplied to a boiler?

Answer—It is best to supply water to the boiler continuously, but if this is not possible, the fireman should add water while the steam is rising, and not when going down, because the added water will cool down the boiler and thereby reduce the steam pressure. Replenishing the water supply should not be delayed to the last moment. The rule given for firing (to charge only a small amount of fuel at a time), is also applicable to the feeding of water; supply a small amount of water often, instead of large amounts at longer intervals.

Question 183—At what parts of a horizontal, bricked-up flue or fire-tubular boiler are the most scales found?

Answer—The most scales are found at the bottom of these boilers a short distance back of the bridge-wall, because at this point the most water is transformed into steam, and, consequently, the impurities lying in the water in solution, are more apt to settle at this point. Scale will also form at the water line, on the top of the fire-tubes, and at the bottom of the boiler in

the rear, but not in such quantities as in the first mentioned case. As a matter of fact, scales can be found at any part of the boiler with which water comes in contact.

Question 184—What is necessary to the cleaning of a boiler?

Answer—The soot and ashes adhering to the main shell, as well as the shell of the flues, fire-tubes and water-tubes must be scraped off. The scale that is caked to the shell must be broken off, and the impurities lying in the boiler must be blown and washed out.

Question 185—What is understood by the blowing out of a boiler; when and how should it be done?

Answer—A boiler can be blown out fully, or partly, while under pressure, by means of the blow-out cock, which should be opened gradually. The boiler should never be blown out entirely, under high pressure; an over-pressure of from five to ten pounds is sufficient for this purpose. A boiler can be partly blown out, even under high pressure. To accomplish this it is necessary to fill up the boiler to the third gauge-cock and allow it to remain at rest for about half an hour, to give the impurities time to settle; an amount of water equal to the quantity between the third and second gauge-cocks, can then be blown out, but care must be taken to open the blow-out cock gradually, so that the pressure in the boiler will not be reduced too suddenly, and so that too great an amount of water will not be discharged from the boiler. Filling the boiler to the third gauge-cock should be done a short time before it is brought to rest; in this way only a small amount of heat is lost, as the cold water at the bottom of the boiler is blown out first.

Question 186—At what time should a boiler be partly blown out?

Answer—The boiler should have at least half an hour's rest before this is done; therefore, noon and night offer the best opportunity for this purpose.

Question 187—How is a boiler cleaned entirely?

Answer—When the boiler has been partly blown out, it must be filled up again to the third gauge-cock, and after the fire is withdrawn it is left to rest over night. The next morning the man-hole cover at the water level, is loosened, the blow-out cock opened, and the water slowly and gradually let out. Instead of loosening the man-hole cover, we may lift the safety-valve, because it is necessary for air to enter the boiler in some way, so that the water may run out. As soon as the water is discharged, the loosened man-hole plate is taken off and the boiler washed out as well as possible by means of a hose leading from a tank, hydrant or hand-pump. Then the

covers of the bottom man-hole, if there is one, and the covers of the mud-holes are taken off and the washing out continued to cool off the boiler and keep the scale moist. When the temperature of the boiler is low enough for a man to enter, he should provide himself with the necessary tools for breaking the scale and cleaning the boiler. These consist of a pick or a hammer and chisel, scrapers, lamp or candle, broom, bucket and a shovel. The medium size bench hammer is the best weight to use for this purpose. The scale must be broken up carefully, the chisel placed radially to the shell, except at rivet heads, where it should not be struck in the same direction as the length of the rivet, but vertically thereto. Where the pick, hammer or chisel cannot reach the shell, scrapers should be used, and places where attachments are joined to the boiler, only scrapers should be used. After the scale is broken loose in this way, it must be brought out of the boiler, which must then be washed again. After this the boiler should be entered again, in order to clean those places, if any, that were overlooked during the first cleaning; and, if after another washing out, no scales can be found, the boiler is completely cleaned inside. Now it must be inspected to find out what damages, if any, have occurred during its use.

Question 188—What damages could happen to the boiler since it was last placed in operation?

Answer—The shell seams or rivet heads may become leaky; the shell may show pittings, grooves, cracks, blistering, bulging or collapsing of the shell.

Question 189—What causes bulging or collapsing of a boiler?

Answer—If part of a boiler shell is covered with scale, and the firing is not gradual, so as to allow the scale to receive the same temperature as the shell obtains, then the shell may get overheated, and even red hot, and becomes weak; then the steam pressure will cause the shell of the boiler, a water-tube, or the inner shell of the fire-box to bulge out and occasion the collapse of a flue or fire-tube.

Question 190—What do we understand by blistering of iron, and where may such blistering take place in a boiler?

Answer—Blistering is caused by expansion of the shell on one side, and contraction on the other; on this account the fibres at about the middle of the shell will separate from each other and form a blister. A shell that is blistered will expand on the side exposed to the heat, and this part is liable to burn up, become brittle, and lose all its elasticity. Whenever the outside of a shell is exposed to heat, and cold water is brought

in contact with the inside thereof, blistering is liable to take place.

Question 191—How do we recognize brittle iron, and what are its qualities?

Answer—For boiler construction, malleable materials should be used. Wrought iron, which is malleable, is composed of fibres, intertwined and twisted like the fibres in a piece of felt, and when broken, the fibre can be noted with the naked eye, but as soon as the iron becomes brittle, it has, when broken, the granulated appearance of cast iron, and the finer the grain, the greater is the brittleness. Such iron loses not only its malleability, but, also, its elasticity, and whenever it is used in a boiler it is liable to cause accidents. A similar objection may be raised against steel and copper when overheated.

Question 192—What is understood by pitting and grooving in a boiler, and what are the causes?

Answer—When the inside shell of a boiler shows excavations in the form of countersinks, we say the boiler is pitted, and when these excavations extend in a line, they form a groove. Both are caused by corrosion of the iron, arising from impurities therein, and the points where such impurities lie are called flaws, as they are not of the same density as the iron, being more porous. They let air and water filter through it, and so cause corrosion of the iron. A single particle of iron, separated by a flaw, may cause pitting and if a fibre is affected the same way, it may cause grooving, if these flaws exist on that surface of the shell which is exposed to water. These affected parts adhere to the scale, and when it is broken off, are carried along with it.

Question 193—What must be done when the boiler is damaged by pitting, grooving, collapsing, bulging or blistering?

Answer—When pittings do not appear in number at one place, but only here and there, holes should be drilled through the shell at these places, a tapered thread cut into the holes and plugs inserted from the inside of the boiler. When drilling these holes or cutting the threads, oil should not be used to keep the tools in temper, but soapy water should be used instead, because the latter can be washed away, while oil would remain, and when blown out under steam pressure, would result in leakage. When pittings appear in great numbers at one place, the sheet must be cut out as far as it is injured, and a patch placed on. The same must be done when the iron becomes blistered or brittle. The method of treating collapsed or bulged iron, by annealing it, and bringing it back as far as possible to its original shape by hammering, is not advisable,

because the shell at that point will not be of equal thickness nor have its original elasticity.

Question 194—How should a patch be attached to the boiler shell?

Answer—A piece of iron of the thickness required by the boiler is cut out so much larger than the hole as to allow a pressure seam of sufficient width for the riveting or screwing of the patch to the shell. This plate should be placed against the inside of the boiler shell after it has been brought to a corresponding shape, and if possible, should be riveted to the shell. Whenever it is not possible to use rivets from the inside of the shell, the patch may be *screwed* on while inside; the patch should be screwed on from the outside only when it is impossible to place it against the inside of the shell. The screw used for this purpose is a machine, and not a plug-shaped screw; it is provided with a "countersink" head, and to this is joined an extension head to fit the wrench. The neck is made small, so that the head is easily cut off after the screw has been driven tight. Whenever it is necessary to use screws, a packing must be placed between the patch and the boiler shell; the packing to be a thin putty, composed of red lead and boiled linseed oil. Hemp fibres are placed around the hole in parallel direction to keep the putty in place and allow it to harden while steam pressure is used. In addition, hemp fibres, saturated with putty, should be placed around the screw holes between patch and shell, and also in the "countersink" made for the screw-head, even if the screw can be clinched at the inside to allow calking of the head from the outside. This is called a cold patch. In no case should a patch to be placed on top of the damaged portion of a boiler shell, because it would act like a blister, and burn off without allowing the heat to penetrate the shell and be added to the water.

Question 195—What may be done when a fire-tube leaks at the point where it is joined to the boiler-head, and what in case it is leaking somewhere along its length?

Answer—A fire-tube that is leaking at the point where it is joined to the boiler head, can be made tight by driving a ferrule into the pipe; and if the pipe is leaking at some point in its length, a plug, made of soft wood, should be driven into each of its ends. The fire-tube will then, in a short while, be filled with water, moistening the wood, swelling it up and making a still tighter fit to the shell; and, although that part of the plug that extends out of the tube, may burn up, yet not any further than the boiler-head. Thus the boiler may be kept in use for a certain time, but, self-understood, only by losing the heat-

ing surface of that tube. Therefore, the tube should be renewed at the earliest convenience.

Question 196—What is the best way to prevent leaking at seams or rivet heads.

Answer—Figures 79 and 80 show, in exaggerated shape, the cause of leakage in riveted seams. Fig. 79 shows a leakage between two rivets and Fig. 80 a leakage at the rivet. Fig. 81 represents the best method of closing a leak by means of a

FIG. 79. FIG. 80. FIG. 81. FIG. 82.

calking tool. An impression is first made with a sharp chisel at the beveled edges of the shell, and then the calking tool is used, so that a kind of flange will be formed at the seam; but if only the calking tool is used, the shells will only meet at one point, as shown in Fig. 82. Whenever the seam cannot be reached by chisel and calking tool from the inside of the boiler, a soft putty of red lead and boiled linseed oil is pressed against the edge of the boiler shell at the seam, and this putty will be forced between the two ends of shell, or between the seam, as soon as the boiler is brought under steam pressure.

Question 197—How can the leakage of a steam or water pipe be prevented?

Answer—By winding around it a rag well moistened with a thin putty, made of red lead and boiled linseed oil, and tying it well, with a hemp string, moistened in the same way. Such a packing is called a soft patch.

Question 198—What is understood by ocular inspection of a boiler, by hammer test, and what is meant by hydraulic test?

Answer—Ocular inspecton means to locate, with the eye, damages which may have occurred in a boiler, such as leakage, pitting, grooving, bulging or collapsing. By hammer-test is meant the sounding of the iron by means of a medium-sized hammer, in order to discover, by ear, any damage that may have taken place in the shell. If tapping the shell produces a clear sound, this proves that the iron is all right, but if the sound is dull, it shows the iron to be rotten; it may be burnt, blistered or brittle. When a hydraulic test must be made on a boiler, it is filled with water to the top. The pump is brought in connection with the boiler by taking out a plug inserted in the top of the boiler for this purpose, and attaching the tube leading from the pump at this point. The safety-valve is then overloaded, so that it cannot open as it ordinarily does when the safe-working pressure of the boiler is exceeded. Then water is pumped into the boiler. Now, this may sound curious, because when the boiler is entirely filled with water, the question naturally arises: "How are we able to bring more water into the boiler, since water is not compressible?" But, if we recollect that running water may absorb air to the extent of 12½ per cent of its weight, we can understand that by the pumping of more water into the boiler this air must be compressed. This compressed air transfers its pressure through the water to the steam gauge, and this will show what pressure is brought to act against the boiler shell.. But the pump must be stopped immediately as soon as a leakage appears in the boiler, or a part of the shell will lose its original shape; to prevent this, the defect must be remedied at once. The filling up with water will be continued until the water sweats through the shell. Of the pressure shown while the shell is sweating, only two-thirds is permissible as a safe working pressure for the boiler; consequently, if sweating of the shell takes place under a pressure of 150 lbs., a safe working pressure of only 100 lbs. is allowed.

Question 199—At what time should repairs be made on a boiler?

Answer—Every repair that may cause concussion, must be prohibited while steam pressure is in the boiler, especially at times when an abundance of steam pressure and steam-ready water can be expected in a boiler.

Question 200—At what time can abundant, steam-ready water be expected in the boiler?

Answer—As long as a boiler is at rest (that is, no steam is taken from it), the water may remain steam-ready in the boiler a good while, and when concussion or rapid use of it takes

place, the steam-ready water can be made at once into steam, filling up the steam-room with a pressure that the boiler cannot withstand. These times are, especially, morning, noon and night. We may set a boiler at rest, which means that no steam is used therefrom, and it will be found that even if no fuel is added, and, in fact, hardly any fuel is left, as happens at noon and night time, the water will receive heat from other sources, as, for instance, from the brick walls, and the pressure in the boiler will begin to rise gradually. But while the water is at rest, all the added heat will not evaporate it, and it remains there as long as the temperature is unchanged and holds it steam-ready. Thus, water, while at rest, is retained from evaporation the same as water is retained from freezing, even though its temperature is already far below the freezing point while at rest.

Question 201—What space must be left between tubes or flues inserted into a boiler head, or between a flue or fire-tube and the edge of a boiler head?

Answer—The distance between two flues or fire-tubes, or between a flue or fire-tube and the edge of a boiler head, should never be more than the fourth part of the diameter of the hole in which the flue or fire-tube must be inserted.

Question 202—How do you calculate the largest size of flue that can be inserted into a boiler, when the flue to be inserted is a single one?

Answer—The smallest space allowed between a flue or tube, and the edge of a boiler sheet, or between two flues is called the weak space, and should never be smaller than one-quarter the diameter of the hole. While two weak spaces are necessary for the insertion of a single flue, two-thirds of the diameter of the boiler head could be used, were it not for the fact that this would diminish the steam room too much and under certain conditions leave hardly any; therefore, the calculation must be made in a different form. Instead of the horizontal diameter, we use the vertical diameter and subtract therefrom the height of the steam room and the height of the water that must lie above the flue. If one-third of the height of the boiler is taken as steam room, this will be abundant. We subtract this, and also, four inches that is the height of the water above the fire-line from the height of the boiler, and four-fifths of the remainder will be the largest diameter of a flue that could be inserted into the boiler, provided the steam room is not made unnecessarily large. We can now calculate the heating surface and judge from that the efficiency of the boiler; if the steam-room is found to be larger than is necessary, the diameter of the flues may be increased.

Question 203—How is the length of the water line at the boiler head calculated when the inner diameter of the boiler and the height of the water stand is given?

Answer—Multiply the two parts of the vertical diameter of the boiler as indicated by the water stand, then take the square root of the product and double it; the result will give the length of the water line. In the same way the length of any chord of a circle can be found, when the two parts of the diameter which intersects this chord at right angles are known. By "chord" is meant a straight line drawn from one point of a circle to another.

Question 204—If the inner diameter of a boiler into which a flue must be inserted is 60 inches, how is the largest size of this flue determined for preliminary purposes?

Answer—While a third of the height of the boiler will give abundance of steam-room, the water-stand must be considered as 40 inches up from the bottom of the boiler. Inasmuch as 4 inches of this must lie above the flue, we subtract these 4 inches from 40, which leaves a remainder of 36 inches, and if we take four-fifths of this,

$$\frac{36\times4}{5}=28\ 4\text{-}5$$ inches would be the diameter of the flue.

As the flues vary only from inch to inch in diameter, either

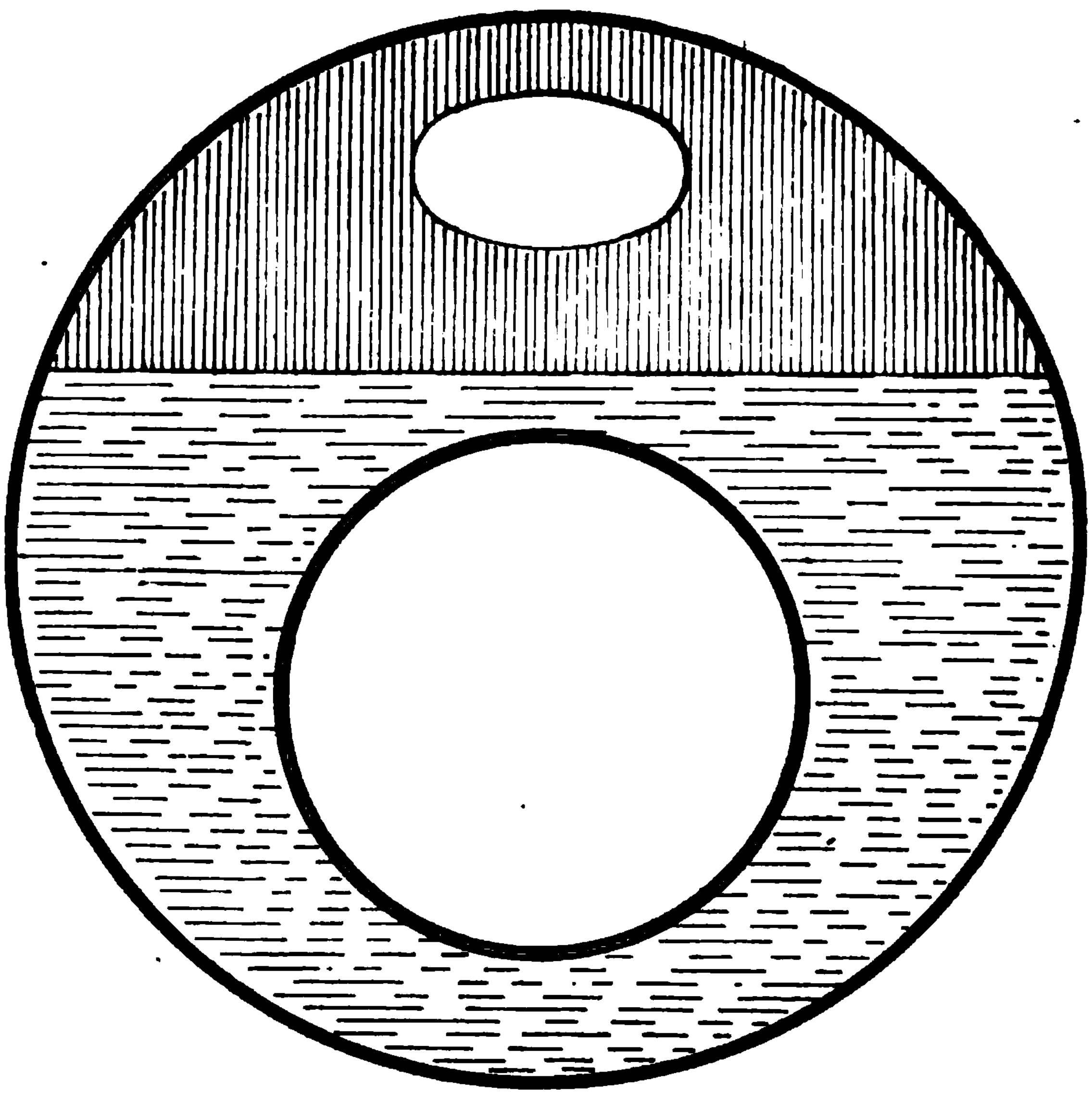


FIG. 83.

28 or 29 inches must be taken as the diameter, and we will select 29 inches for reasons explained in the next calculation.

Question 205—What number of square feet heating surface has a horizontal boiler of 60 inches inner diameter, and 300 inches length, into which one flue of 29 inches diameter must be inserted when 100 lbs. steam pressure is used, the shell single-riveted, and the tensile strength thereof is 60,000?

Answer—A flue of 29 inches diameter requires a weak space of $7\frac{1}{4}$ inches, which is the fourth part of the diameter of this flue. As we need above the flue four inches of water, we add the 29, $7\frac{1}{4}$ and 4 together, which shows that the water stand is $40\frac{1}{4}$ and the fire-line $36\frac{1}{4}$ above the bottom of the boiler. Compare with Fig. 83. For calculating heating surface, we first figure the outer diameter of the boiler and the inner diameter of the flue. That part of the tensile strength which must be taken into consideration according to the seam, for the outer shell as well as for the shell of the flue, 10,000; for the main shell

$$\frac{30\times100}{10,000}=0.3 \text{ inches is obtained,}$$

which makes the outside diameter of the main shell of the flue we need:

$$\frac{29\times100\times300}{2\times10,000\times5\times29}=0.3 \text{ inches;}$$

therefore the inner diameter of the flue=28.4 inches. If we now intend to calculate the heating surface of the outer shell, we take first half the circumference of the outside cylinder; this will be:

$$\frac{60.6\times3.1416}{2}=95.19.$$

We add to this twice the distance between the fire-line and the horizontal diameter at the outer shell, which is $2\times6\frac{1}{4}$ =12.5, making a total of 107.69. This, multiplied by 300, the length of the boiler, and divided by 144, gives:

$$\frac{107.69\times300}{144}=\frac{32307}{144}=224.35 \text{ feet.}$$

The heating surface of the flue shell will be:

$$\frac{28.4\times3.1416\times300}{144}=185.87 \text{ square feet.}$$

We now add the outer and inner heating surfaces together, and have then a total of 410.22 square feet heating surface in the boiler, because the surface of the boiler-heads, which are exposed to the fire, are not counted as heating surface, while the sheets used for them are of such thickness, that heat is not able to penetrate them to any appreciable advantage.

Question 206—How do we determine the number of cubic feet of steam-room that a horizontal cylinder boiler of 60 inches inner diameter must have when a flue of 29 inches diameter is inserted?

Answer—The answer to the last question shows that the total heating surface of the boiler amounts to 410.22 square feet. The construction is one of the simplest kind, therefore it is assumed that 14 square feet are needed to transform one cubic foot of water into steam. If 410.22 is divided by 14, the result is $410.22 \div 14 = 29.3$ cubic feet of water which can be transferred into steam per hour in this boiler. The steam-room is calculated on a basis of four atmospheres real pressure steam. The table below shows that each cubic foot of water will make 475,358 cubic feet of steam. Then multiply 475,358 by 29.3 to find the number of cubic feet of steam that are developed in an hour's time; to find the amount developed in a second's time, divide this by 60×60, and multiply the quotient by 3, and the result will be the least number of cubic feet that the steam-room must contain:

$$\frac{475{,}358 \times 29.3 \times 3}{60 \times 60} = 116.066 \text{ cubic feet.}$$

This is the amount of steam the boiler can generate in three seconds' time.

Question 207—How do you calculate the steam-room that a horizontal boiler of 60 inches inner diameter shall contain in cubic feet, if a flue of 29 inches is inserted, and as a consequence the water line stands $40\frac{1}{4}$ inches above the bottom of the boiler?

Answer—We calculate first the length of the water line and the length of the fire-line. The water-line is found as follows: $40\frac{1}{4} \times 19\frac{3}{4}$, the square root taken of this product and the result doubled, which will give $2 \times \sqrt{40\frac{1}{4} \times 19\frac{3}{4}} = 56.38$ inches. Then we calculate the fire-line as follows: $36\frac{1}{4} \times 23\frac{3}{4}$, the square root taken of this product and the result doubled will be $2 \times \sqrt{36\frac{1}{4} \times 23\frac{3}{4}} = 58.68$ inches. After we have determined the length of these lines, we calculate the area of that part of the boilerhead against which the water lies; first, below the horizontal diameter, then between the horizontal diameter

and the fire-line and then between the fire-line and the water-line. If we add these three areas together, and substract the sum thereof from the area of the boiler head, we have as a remainder that part of the boiler head against which lies the steam. If we then multiply the area of the steam-room lying against the boiler head by the length of the boiler, we have the cubic contents of the steam-room in cubic inches, and these, divided by 1,728, give the steam-room contained in the boiler in cubic feet. The area at the boiler-head below the horizontal diameter amounts to:

$$\frac{60 \times 60 \times 11}{14 \times 2} = 1414{,}2857 \text{ square inches.}$$

The area at the boiler head between the fire-line and the horizontal diameter is $(60+58.68) \times 6\frac{1}{4} \div 2$, or:

$$\frac{118.68 \times 25}{4 \times 2} = 370{,}875 \text{ square inches.}$$

The area at the boiler head between the fire-line and the water line is $(58.68+56.38) \times 4 \div 2$, or:

$$\frac{115.06 \times 4}{2} = 225.12 \text{ square inches.}$$

The area of the boiler head is:

$$\frac{60 \times 60 \times 11}{14} = 2828{,}5714 \text{ square inches.}$$

If we subtract from this latter amount 2828,5714, the sum of the three before mentioned areas, which is $1414{,}2857+370{,}875+225.12=2010{,}2807$, there remains $2828{,}5714-2010{,}2807=818{,}2907$ square inches as the area of the steam-room meeting the boiler head. If we multiply this remainder by the length of the boiler, namely, by 300, and divide the product by 1728, we have, as a result, the capacity of the real contents of the steam-room in cubic feet, namely:

$$\frac{818{,}2907 \times 300}{1728} = 142{,}064 \text{ cubic feet.}$$

An abundance of steam-room is shown here, which allows the increase of the size of the flue. When this is done, we must recollect that we always raise the water stand $1\frac{1}{4}$ inches for every inch added to the diameter of the flue, thereby increas-

ing the heating surface and diminishing the steam-room. If the resulting steam-room is insufficient for amount of water evaporated, then the size of the flue must not be increased. It is not advisable to make the steam-room only so large that it will hold only the steam generated in three seconds' time, especially if the boiler is not used at the same time for power and for other purposes, such as heating, drying or cooking, because an unskillful handling may cause a too sudden use of the steam, and therefore, foaming of the boiler.

Question 208—If it is decided to place a number of flues in a row, for instance, 3 flues into a boiler of 60 inches diameter, how do you calculate the largest size of flues permissible?

Answer—We decide this by the horizontal diameter, recollecting that we always need one more weak space than we have flues; in this case we have, consequently, three flues and four weak spaces. Each weak space represents a quarter flue, which is the same as if four flues were placed tightly against each other in the diameter of 60 inches. The fourth part of 60 is 15, therefore we decide that the largest size of flue can be 15 inches, provided we are able to leave sufficient steam-room. 7½ inches of these flues stand above the horizontal diameter of the boiler, consequently the fire-line extends 37½ inches above the bottom of the boiler, the water-line 4 inches above this, and therefore brings the water-line 41½ inches above the bottom. We judge from former calculations that we have, by all means, sufficient steam-room.

Question 209—How do you decide how many rows of flues or fire-tubes we are able to insert into a boiler; for example, can we insert in this 60-inch boiler two rows of flues of 15 inches diameter?

Answer—Whenever we are required to fix the number of rows of flues, it must be recollected that there are two ways to insert rows; either the flues or tubes may lie in an irregular, or zigzag position. In the first case, the lines in which the centers of the flues lie must be at a distance of 1¼ times the diameter of the flue; in the zigzag position the lines must be at a distance from each other equal to 1.172 times the diameter of the flue. In addition to the weak spaces, a distance equal to a quarter of a flue must be left between a flue and the main shell, in both cases. In case where a second row is to be placed below the first, in zigzag position, a distance of equal to 1.172 of the diameter of the flue must be observed between the diameters of the two rows and the flue nearest to the shell must remain at a distance at least one-quarter of the diameter of the flue. To ascertain that the

flue, which comes nearest to the main shell, is at a distance therefrom to the extent of a weak part, we draw a radius from the center of the main shell through the center of the flue that is in doubt. (See Fig. 84.) When we subtract from that radius $1\frac{1}{4}$ times a flue, and if the remainder is then $\frac{3}{4}$ of the flue, the flue lies at a sufficient distance from the shell; this is here the case, and we are so able to place two rows, or five flues into the boiler. But if we intend to place the flues vertically to each other, it would have been possible to place only one flue in the second row, as shown by the dotted lines in the same figure.

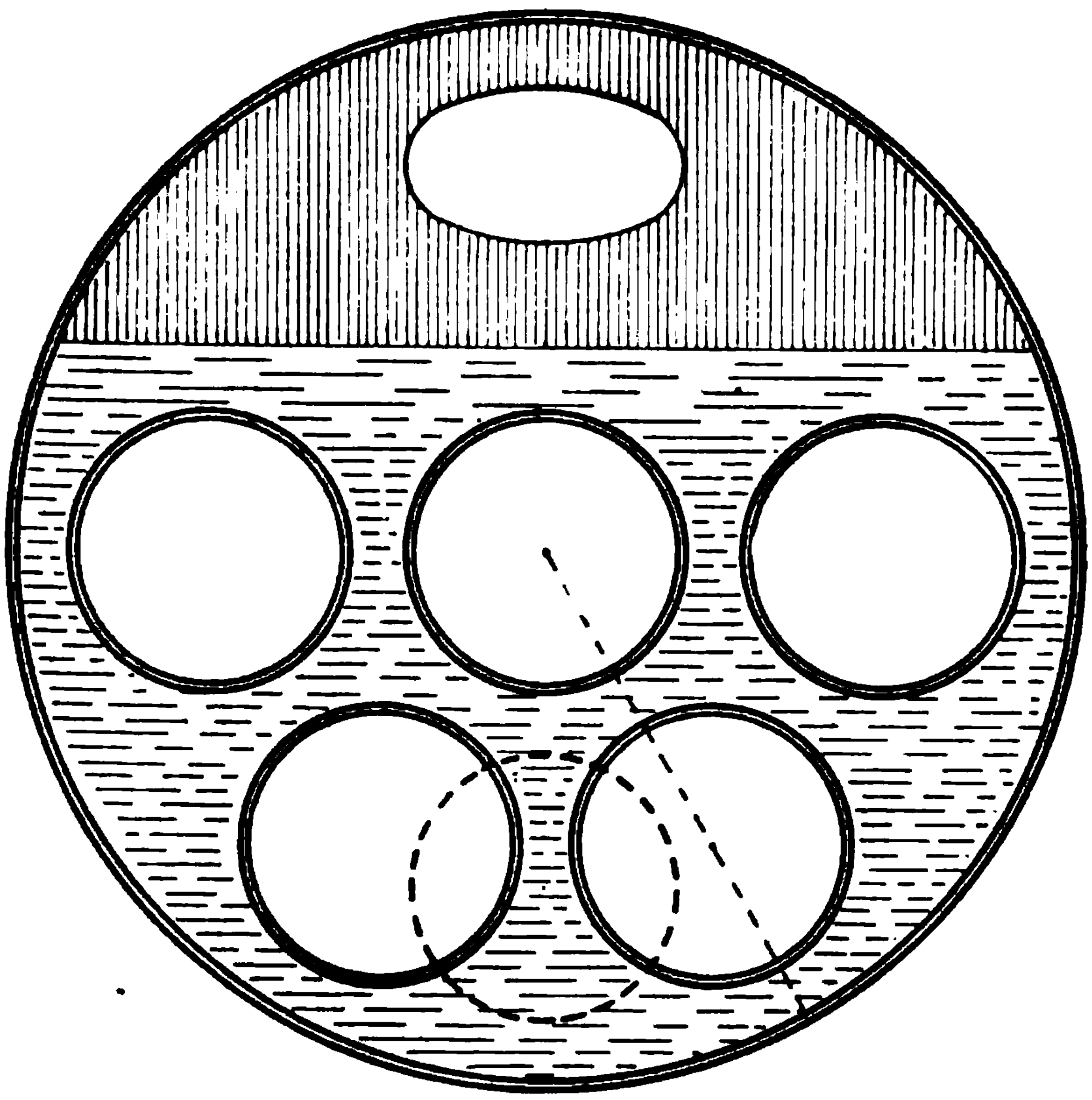


FIG. 84.

Question 210—How many four-inch fire-tubes can be inserted in a boiler of 60 inches diameter?

Answer—We need for each tube a weak space, but for each row an extra space; we use for one tube and one space, together five inches; and as often as this five is contained times in 60, so many tubes can be inserted in a horizontal diameter, provided that a remainder of one inch is left for the extra weak space. Now, 5 is contained in 60 12 times, but as it leaves no remainder, we are able to insert in the horizontal diameter of this boiler only 11 tubes, and while these tubes and spaces with the

extra weak space occupy only a length of $11\times5+1=56$ inches, we have on each side of the row an extra free space of two inches. If we draw a line two inches away from the circumference, vertical to the horizontal diameter, we have a chord equal to two times the square root of the product of two times 58, which is $2\times\sqrt{2\times58}=21.54$ inches. In this length we are able to place the top row of tubes as high as the steam-room will allow, and the other rows vertically below this; but while this boiler will have a greater heating surface, and generate therefore a great deal more steam than the boiler for which we calculated only a single flue, it may be advisable to have the water line at 2-3 the height of the boiler. We

Fig. 85.

deduct from this two-thirds, consequently from 40, at least 6 inches as a layer of water above the fire-line. There remains then only a height of 34 inches for the top of the highest row. Five is contained in 34 only 6 times, therefore only 6 rows can be placed. But if the calculation shows that the steam-room is larger than required, and the water line can be taken an inch higher, seven rows of fire-tubes may be inserted. If six rows are used, the top row is placed just above the horizontal diameter, and three rows with 11 tubes each can be inserted, the fourth row contains 9 tubes, the fifth row

7 and the sixth row 5, making a total of 54 tubes. (See Fig. 85 on page 100.)

We could place six more tubes, consequently 60, if we placed the three lower rows zigzag to each other, in which case the fourth row would contain 10, the fifth row 9 and the sixth row 8 tubes. (See Fig. 86.)

FIG. 86.

FIG. 87.

Question 211—How many four-inch fire-tubes can be inserted in an upright boiler, the fire-box of which has a diameter of 36 inches?

Answer—Here is also needed for tube and a weak space 5 inches and as often as 5 is contained in 36, that number of flues can be placed in the middle row, provided an extra space of one inch remains. Five is contained in 36 7 times, leaving a remainder of one inch; therefore, we are able to place in the diameter of this boiler 7 tubes and can place on each side three more rows, and if we arrange the flues in zigzag position, the middle row will have 7 tubes, the next two 6 each, the two following 5 each, and the last two rows 4 tubes each, making a total of 37 tubes, as shown in Fig. 87 on page 101.

Question 212—What is understood by a battery of boilers?

Answer—If a great power is required, a single boiler of the proper capacity would demand sheets of too great a thickness, and in such case it is preferable to join two or more small boilers together, which have in sum the capacity required. Whenever such an arrangement is made, it is called "a battery of boilers."

Question 213—How many different types of batteries do you know, and how do they differ?

Answer—We have two types of batteries. In the one kind all boilers must be used together and must also be set at rest together. The second type is arranged so that any single boiler may be dropped, which means, be brought to rest, while the balance can remain in use. The easiest way to decide which of these types is before us is to inspect the furnace. In the first mentioned type, a mutual fire-place will be found, while in the second each boiler has its separate furnace, and a partition wall is erected between each pair of boilers.

Question 214—How are the boilers in a battery combined?

Answer—There is a mutual water supply pipe and a mutual steam conveying pipe connecting all the boilers by means of branch water pipes and branch steam pipes. Instead of the mutual steam conveying pipe, a mutual steam drum is used sometimes, to which the branch steam pipes lead.

Question 215—Is the water supply pipe in a battery of boilers constructed the same as in single boilers?

Answer—The mutual water supply pipe of a battery of boilers contains neither a check-valve nor a stop-cock or globe valve. But in each branch water pipe a check-valve must be inserted, and between it and the boiler a stop-cock or globe valve.

Question 216—Must this arrangement in the water branch pipes also be made in a battery where the boilers cannot be operated from each other?

Answer—It is required in both types.

Question 217—In a battery of boilers that cannot be separated does it not appear advisable to have the check valve and the stop-cock only in the main water supply pipe?

Answer—It seems so, at first thought. The single boilers in a battery are placed so that each boiler has its fire-line in the same horizontal line with the other boilers. Water stands at the same height in the whole battery. If one boiler receives more water than another, or one boiler evaporates more water than another, the water finds its own level. That one boiler can receive more water than another can be proven as follows: The boiler nearest to the water feed apparatus will receive more water than one that lies at a greater distance from it, on account of the friction of water in pipes, and the water branch pipes possibly being more or less obstructed. Besides more water may be used out of one boiler than another, because the heat applied to the boilers is not always equal; therefore, it would be very desirable if the water could find an equal level automatically, which would be the case if no check-valves were placed in the branch pipes, but only one in the main water supply pipe. When it is considered that one boiler of a battery may sink on account of settling of the ground, we know that the boiler that has been thus lowered would always receive too much water, while those remaining in the original position might not have enough. This shows the necessity of having in the branch water feed pipe of each boiler a check-valve, consequently, also a stop-cock or globe valve.

Question 218—Is it necessary that the other water controlling attachments be also placed on each boiler, whether the battery is constructed for separation or not?

Answer—All five water controlling attachments are needed on each boiler in both types of battery.

Question 219—If one boiler receives more fire than another it is bound to generate more steam, and, consequently, use more water; obstructions and friction may prevent a boiler from receiving the necessary quantity. How can it be arranged so that the water in every boiler will stand at the proper height above the fire-line?

Answer—As each branch water feed pipe is provided with a stop-cock or globe valve, we may cramp the water supply pipe of any boiler until the water stand is equalized.

Question 220—Why must each branch blow-out pipe in a battery of boilers be provided with a blow-out cock?

Answer—If we placed only one blow-out cock in the main blow-out pipe, the boilers would communicate and the water level could not be kept at the proper height in each boiler, in case any of the boilers settled.

Question 221—Why do we use for each boiler of a battery, three gauge-cocks and the water-glass?

Answer—We would be entirely in doubt as to the water stand in each boiler, if we did not have these attachments on each boiler.

Question 222—Why must fusible plugs be placed in each boiler of a battery?

Answer—Because there is a chance of the water going out of sight in each of the boilers and leaving the heated surface uncovered with water.

Question 223—How must the steam controlling attachments be arranged on a battery of boilers when the single boilers cannot be separated from each other?

Answer—We affix all three steam controlling attachments (steam-gauge, steam-valve and safety-valve) to the mutual steam conveying pipe, or the mutual steam drum; as the steam-rooms of the boilers are at all times in direct communication, this arrangement is sufficient.

Question 224—How do we place the steam controlling attachments into a battery in which single boilers can be separated?

Answer—In such a battery we place a steam valve in each branch steam pipe, and at the highest point of the steam-room of each boiler we place a steam-gauge and a safety-valve.

Question 225—Is it not sufficient to have one safety-valve in a battery which can be disconnected if it is placed on the mutual steam conveying pipe or the mutual steam drum?

Answer—Such a single safety-valve would do as long as all the boilers are kept in use, but the boiler, which for some reason is separated, is not dropped forever. After the cleaning or repairing of a separated boiler is done, the intention is to join it to the battery again, and we should not be able to start up the boiler without having a safety-valve, because we may raise the pressure in the boiler above the safe working pressure.

Question 226—Would not a steam gauge be sufficient on each boiler of a battery which can be separated for the purpose of again starting that boiler which had been dropped?

Answer—We are not able to depend absolutely on the steam gauge, and, therefore, it cannot be allowed to use only a steam-gauge without having a safety-valve on each boiler.

Question 227—How must a single boiler be disconnected from the battery?

Answer—We first close the steam-valve in the branch steam pipe, but slowly and gradually, and after the water has been raised to the third gauge-cock, close the stop-cock in the water feed branch pipe.

Question 228—What is the best mode of arranging the branch steam pipes to the mutual steam conveying pipe or steam drum, and to the boilers?

Answer—It is not advisable to join boiler and conveying pipe or steam-drum by a straight pipe; there must be an arrangement on the branch steam pipe that will allow motion of the steam conveying pipe or drum, connecting a row of boilers, because the conveying pipe, as well as the steam drum, will be expanded as soon as steam heats them up, while the middle lines of the boilers remain at the same distance from each other

FIG. 88.

as they are when put up. Fig. 88 explains a good arrangement for such a steam branch pipe with a steam valve inserted. A represents the mutual steam pipe or steam drum; B the steam valve and C the dome of one boiler of the battery. The thread in the vertical tube, in which the steam valve is inserted, allows it to turn on the boiler, while the thread of the vertical tube leading to the drum allows this also to turn; both tubes are joined by elbows, and a horizontal pipe, which latter can be drained before taking the boiler in use, by a cock, D, generally called a bleeder.

Question 229—How do we brick up and mount a single horizontal flue or fire-tubular boiler, or a battery of the same?

Answer—We first get the correct dimensions of the boiler to lay out on the ground, the marks for digging the foundation, and also decide thereby the position of the side walls, as well as the partition walls, which shall be at a distance of at least four inches from the boiler; also to fix the position of the rear

FIG. 89.

wall, which must stand away from the boiler at least eighteen inches. After deciding the position of the side and partition walls, the rear walls and fire-front, we must also determine the position of the bridge-wall and the pillow. The position of the bridge-wall depends on the size of the grate surface which we wish to get, and the pillow will be placed at a distance of three-fourths of the length of the boiler from its front. We now dig out the ground to allow for a deep and broad foundation for the fire-front and pillow, and a smaller, and not quite as deep a foundation is required for the side-walls, partition wall, rear wall and bridge-wall. The earth should be dug out until we strike solid ground, or make it so by driving piles, then bring the foundation for fire front and

pillow (according to the size of the boiler) at least three feet under ground. For side, partition and rear walls, as well as for bridge-wall, the depth of the foundation will be made from one to one and one-half feet. The foundation should be made from three to four inches broader than the thickness of the wall. The brick walls of a boiler should never be thinner than twice the length of a brick. For the foundation, a layer of concrete is first placed in the ground, and after this has settled the stone walls can be placed on top, well joined with cement and sand. The rock foundation is brought above the ground for about three or four inches for the purpose of leaving the brick work entirely free from contact with water, which

FIG. 90.

already may be contained in the ground, or settle there afterwards by cleansing the boiler; this water may fill up the fire-place with vapor, and so obstruct the draft. It is advisable before the brick work is done to place a layer of tar paper on the stone work; this is always done for the purpose of preventing moisture from the ground entering the bricks. It is important that the bricks used are always kept dry as possible. The bricks selected for that part of the wall which the fire is not able to reach should be hard bricks, because they do not absorb moisture; they should be joined together with a mixture of common mortar and cement, and special care should be taken that no air spaces are left between the bricks, all the spaces being entirely filled with mortar. The joining of the bricks must not be done as in the building of houses, where a number of rows are laid in one direction before a cross layer

is made, but in bricking up a boiler, one layer of bricks must always cross the other before going on. Where the fire, or heated gases are able to strike the brick walls, fire-bricks must be used, joined together by a mixture of fire-clay, with powdered fire-bricks. This cement between the single bricks shall

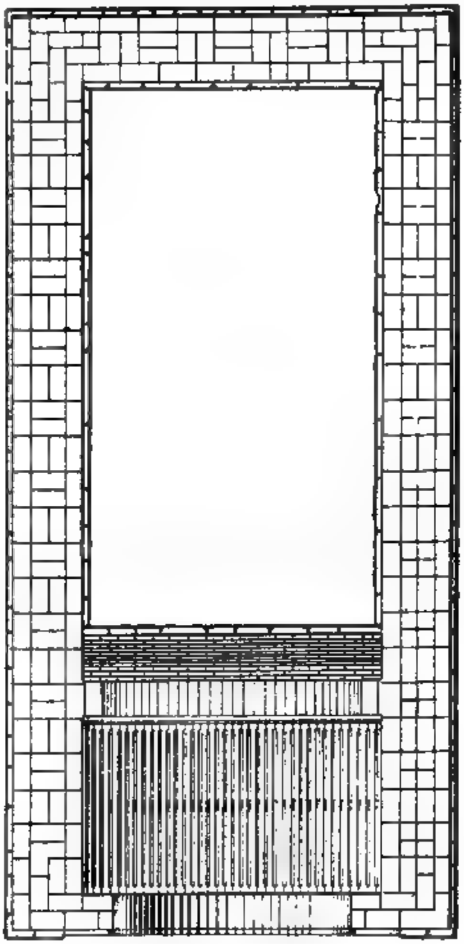


FIG. 91.

entirely fill up the spaces, but it must be put on as thin as possible; the single bricks should be well rubbed or squeezed against each other, so that only a small amount of fire-clay lies between them, otherwise the bricks would become separated

from each other, because fire-clay will shrink when exposed to heat. The side walls, rear walls and partition walls will be built up to the height of the fire-line of the boiler, and the fire tubes must be arched over from the side or partition

Fig. 92.

walls to the boiler, so that the lower side of the fire-tile meets at the fire-line of the boiler; where a fusible plug is used in the outer shell of the boiler, the tile must be arranged at this place so as to allow the steam to escape into the boiler furnace without obstruction. Before the brick work is commenced, the boiler will be blocked up in the right position on the ground. The fire-front is placed below the front of the boiler,

and care must be taken that that part of the boiler, out of which the flanges extend, comes in front, and that each boiler lies with its flues, or fire-tubes, in level crossways, and that all top rows of boilers in a battery are the same height. Then the pillow will be placed below the boiler, leaving it in an incline towards the rear one inch for every ten feet. According to this position, the brick work must be done after all attachments are placed. We build a bridge-wall below the grate-bars with hard brick, vertically up to the grate-bars, which should be placed in level, and a sufficient distance below the boiler, according to the fuel to be used, for soft coal, the space

FIG. 93.

of 19 inches; the bridge-wall will be built above the grate-bars out of fire bricks, joined with fire-clay, as before mentioned. But this wall must not be raised up vertically. It must be placed obliquely to the grate-bars, leaning a little towards the rear, so that the top of the bridge-wall, which may be placed either horizontal or parallel to the boiler, will be in an incline towards the rear. (See Fig. 93.) This is done to the end that coal or soot that would otherwise rest on top of the bridge-wall, may be blown by the draft towards the rear of the bridge-wall and discharged, at once, into the soot pit. The fire-front must be lined with fire-brick, as far as its face is exposed to the fire. The boiler must be raised high enough from the ground that the ash-pit lying below the grate surface, cannot be easily filled with ashes so high that the draft

would be obstructed, and the room behind the bridge-wall must be sufficiently deep, so that the soot falling there cannot obstruct the draft, and to not only permit the free entry of a man behind the bridge-wall to carry out soot settled there, but he must, also, be able to clean the outside shell and inspect its merits or any damage done to it. An opening in the rear of the side-wall, which can be closed air-tight, must be left as an entrance to the soot-pit. When a mud-drum is attached to a boiler it must be arched over by fire-bricks, so that no fire and no heated gases can touch it. (See Fig. 89, page 106.) A boiler should never be bricked up in such a way that one of its walls would be adjacent to another building. A free passage must be left all around a boiler, and there must be ample room in front of it to handle the shovel while feeding fuel.

The Fig. 90, page 107, and Fig. 91, page 108 fully explain the direction of a bridge-wall, and the Fig. 92, page 109, shows a longitudinal section of the boiler while bricked up, and Fig. 93 shows the cross-section of a bricked-up battery of boilers at the place where the grate-bars lie, at which the single boilers can be separated from each other.

Question 230—Which is more preferable, to have a bridge-wall placed horizontally on a boiler or parallel to it?

Answer—When the bridge-wall is placed horizontally, it forms angles with the side-walls' angles, the vertex of which lies at a greater distance from the boiler than the sides of the walls. Now, heated gases have no tendency to fall down; they have only a tendency to ascend. The consequences of this arrangement would be, that the heated gases which lie at a greater distance from the boiler, could not give up their heat as readily as those that lie closer to it. Unnecessary heating of the side-walls would be the result, consequently a great heat would be spent for a wrong and useless purpose. Besides, the same space between the bridge wall and boiler would be larger than the sum of the area of the flues, and so cause obstruction of the passages in the flues or tubes of a boiler; all this may be avoided by placing the bridge-wall in a circular position, parallel to the boiler.

Question 231—How do we put up a bridge-wall parallel to a boiler, the inside diameter of which is 60 inches and into which 60 four-inch flues are inserted, which stands under 100 pounds pressure, as illustrated in Figs. 94 and 95?

Answer—We have to calculate first the areas of these flues, to decide what space we have to leave between boiler and bridge-wall. It may be remembered that the thickness of the main

shell, as well as the thickness of the tubes is three-tenths of an inch. The sum of the areas of the flues is consequently:

$$\frac{3.4 \times 3.4 \times 11 \times 60}{14} = 544.97 \text{ square inches.}$$

Then we calculate the area which is formed by the outer diameter of the main shell:

$$\frac{60.6 \times 60.6 \times 11}{14} = 2885.42 \text{ square inches.}$$

The 544.97 square inches, which is the area of the flues, represents the space between bridge-wall and boiler, and part of a ring surroundng the boiler. We recollect that the fire-line in this boiler lies four inches above the horizontal diameter of the boiler, and while half the circumference is

$$\frac{60.6 \times 22}{7 \times 2} = 95.2286 \text{ inches,}$$

we must add 8 inches to this, amounting to 103.2286 inches of the circumference of the main shell exposed to the heated gases. That part of the ring through which the heated gases pass, has on its inner side a length of 103,2286 inches, while

FIG. 94.

the whole length of the inner side amounts to 190.4572. For the whole ring surrounding the boiler we require:

$$\frac{544.97 \times 190.4572}{103.2286} = 1005.46 \text{ square inches.}$$

Now, if we add this 1005.46 as the area of the ring to the 2885.42 as the area of the circle inside of the ring, we would get as the total area, 3890.88 square inches, and if we divide this number by 11/14, we will ascertain the area of the square erected on the diameter of this circle, equals 4952.0291 square inches. If we take the square root of the figure, we find the

FIG. 95.

diameter of the outer circumference of the ring: 4952.0291 equals 70.39 inches. If we subtract from this the diameter of the outer shell with 60.6 and divide the remainder by 2, we will get the thickness of the ring, representing the distance between the bridge-wall and the boiler, as:

$$\frac{70.37-60.6}{6} \text{ or } \frac{9.77}{2} = 1.885 \text{ inches.}$$

Now we form a templet in the shape of a half ring, the inner circle of which will be formed by the radius of the main shell, namely, 30.3 of an inch. To form the outer circle we add to this the space calculated, namely, 4.885, and the width

of a fire-brick, which is 4.25 of an inch; the radius of this outer circle must therefore be 30.3+3.885+4.25=39.435 inches. We must make this templet stationary below the boiler at a place where the bridge-wall is to be erected, and fill up the space below it with bricks lying in horizontal position, then we take out the templet and form an arch over the brick work, as illustrated in Fig. 95 on page 113. The side or partition walls must, in this particular construction, be 4.885 inches, or better, 5 inches away from the boiler.

Question 232—How must a boiler, provided with a bridge-wall parallel to it, be attended to, and what advantage, if any, will it afford then over one with horizontal bridge-wall not so attended to?

Answer—When a boiler, provided with a bridge-wall lying parallel to it, is partially blown out twice a day, at noon and at night time, and emptied every fourteen days, the loose scales found a short distance behind the fire-bridge, which often result in burning the shell at that place, taken out, and the boiler well washed out, a thorough cleaning will not be necessary oftener than every six weeks. With this attention 15 to 20 per cent of the fuel otherwise required will be saved.

Question 233—We have stated that a sudden decrease of steam pressure in the boiler would cause foaming; now, what may cause this sudden decrease of steam pressure?

Answer—There are several causes for it: 1. If the steam-room is suddenly exposed to a cool draft, rain, etc., it will be cooled off quickly, and as a result, the sudden decrease of pressure on the water takes place. 2. If a steam engine, a steam pump, a heating, cooking or drying apparatus is brought in connection with a boiler, by opening the respective steam valve at once, an abundance of heat is required to bring the different mechanism or apparatus to the same temperature that the steam in the steam-room of the boiler has, and so a very rapid foaming of the boiler will take place. Therefore, joining such mechanism or apparatus to the boiler, must be attended to with caution, very slowly, so that the flow of heat may be gradual, and too much cannot be used from the boiler at one time. 3. In a boiler that is poorly atended to, irregularly cleaned, and not gradually fired, and wherein, consequently, a great amount of scale will prevent the transfer of heat to the water in due time, overheating, even burning of the shell will take place; the scale will break off from the shell as it shrinks and shrivels by heat, while the iron is expanding; the whole over-heated surface comes in contact with water which is made steam-ready at once. This steam-ready water is driven with great velocity

forcing the colder water which lies above, into the steam-room, thus suddenly cooling off the latter. 4. If a boiler shows water above the third gauge-cock, which must be blown out under high pressure, and the blow-out cock is quickly, and entirely, instead of very slowly, gradually, and only partly opened, the suddenly vacated room will cause a sudden decrease of pressure in the boiler. 5. If in a battery of boilers, two that are standing under different kinds of pressure are connected; for instance, one has 60 lbs. and the other has 100 lbs. steam pressure, both having equal steam-room, and the connection takes place suddenly, the steam in both boilers will at once be of 80 lbs. pressure. Thus, in one boiler, the steam is suddenly reduced from 100 lbs. to 80 lbs., and is bound to foam and transfer its water to the other boiler. 6. If a boiler has only the minimum of steam-room, and the temperature in an engine requires too much reheating of the materials at every stroke, a slight foaming may take place in it. Therefore, a steam-room of only minimum size, that is, no larger than the rule prescribes, is not advisable, especially if several different kinds of machinery, or apparatus require the steam.

Question 234—Is foaming dangerous?

Answer—A slight foaming in the boiler is not dangerous, as long as the engineer attends to the regular water supply, but as soon as the foaming approaches a stage of violence, it extends into the steam conveying pipe, and the water may be emptied out of the boiler in a short time, running through the steam conveying pipe which acts as a syphon. The heating surface may be covered only by foam, and can be overheated, and bring the boiler in danger as soon as cold water is supplied and before the water stand has been decided again. Such a violent ebullition will be caused especially by muddy or greasy water.

Question 235—By what means can we ascertain that the water in the boiler is foaming?

Answer—As long as the boiler is generating steam the water makes no ebullitions and only its vibrations are shown in the water glass as long as steam is used from the boiler, and it is, therefore, clean in the water glass, while the sediments in it had been settling on the bottom during the time that the water was at rest; the fine impurities, which by the separation of steam from them are rendered finer than dust, are heavier than water, and when the water is not in violent motion as in ebullition, they gradually settle and the water appears clear, but as soon as a violent foaming takes place, the mud which had been laying at the bottom of the boiler, and on the top

of the flues, is stirred up, and gives the whole water a dirty appearance, even in the water glass. Thereupon, and especially as soon as air bubbles appear in the water glass, and it appears filled with bubbles, we may be sure that the boiler is foaming. If we hear a roaring noise in the boiler similar to that when the water is boiling, as is sometimes the case if we keep the third gauge-cock open in the morning while starting the boiler, while steam is being generated, the boiler is foaming. If in the steam conveying pipe a noise like hail falling on a roof is heard, the boiler is foaming. A creaking or clinking noise in the steam proves that there is water in it and at every stroke of the engine the drip-cocks discharge an extra amount of dirty water, the boiler is foaming. Notice the exhaust pipe, and if you discover water falling like rain from the exhaust steam, the boiler is foaming. When the water in a boiler goes down unnaturally quick, while at the same time the water feed apparatus is working in good order, and there is no leakage in attachments or the boiler itself, the boiler is sure to be foaming.

Question 236—Can the foaming in a boiler be prevented?

Answer—Foaming in a boiler can be prevented by adopting in practice the following suggestions: As far as possible, the boiler should always be kept free from mud and scale; therefore, it should be partially blown out twice a day and thoroughly cleaned at reasonable intervals. When starting the boiler, the fire should be gradually raised, and sufficient time given to the shell to transfer its heat through the scales, when they are not avoidable. Fire should be reasonably handled always; it should never be choked up or smothered, and it should never be stirred to make it sheer. A steam valve should always be opened a very little at the start only, when boilers in a battery are to be connected, or when any kind of machine or apparatus in which steam is used is brought in connection therewith, and for any such purpose the valve must be opened slowly and gradually, until sufficient steam is in motion. The boilers should never be connected together if they are different in pressure. The boiler should never be entirely blown out while it is under high pressure, and when blowing it out partially, great care should be taken that the passage is gradually enlarged. The steam-room and the conveying pipe of a boiler should be well covered with non-conducting materials, such as mineral wool, or better, with asbestos. The steam cylinder should also be well jacketed.

Question 237—How do you attend to a foaming single boiler?

Answer—When a boiler is violently foaming, the main object is to save the water that is in it. Therefore, the steam conveying

pipe must be closed by its valve, but slowly and gradually. The water supply may be stopped, especially if the foaming is not discovered at the start. Then the draft may be moderated and the boiler brought to rest until the foaming stops. It is best to have the boiler at rest about half an hour, and then if water is in sight, the boiler may be put in operation again. But if this is not the case, the fire must be covered with wet ashes, and when the boiler has cooled down, and the steam pressure is reduced to about 10 lbs., the boiler may be slowly blown out, washed out, cleaned, and inspected, so that if any harm has been done to it by foaming, repairs can be made at once; and when everything is in order, the boiler may be filled up with water to the first gauge-cock and put in operation again.

Question 238—If, in a battery of boilers, you observe one foaming, what must you do if the battery can be disconnected, and what, if it cannot?

Answer—When, in a battery, a single boiler foams, the whole battery is foaming; therefore, it is immaterial whether the battery can be disconnected or not; it must be considered as a single boiler and managed as such.

Question 239—What are you bound to do, if, in a single boiler, a fusible plug melts out?

Answer—You can really do nothing with it. The steam from it enters the fireplace at once, fills up all the passage, obstructs the draft and extinguishes the fire. Then all the machinery comes to rest of itself. So when this emergency arises, just wait till the steam leaves the boiler entirely, then discharge the water out of it, clean it, and renew the fusible plug. When the boiler is fed by hydrant pressure, it is proper to shut the water supply pipe as soon as the accident happens to avoid waste of water.

Question 240—What must be done, if, in a battery of boilers that cannot be disconnected, the fusible plug melts out of one of them?

Answer—We have, in such a battery, a mutual fireplace. The fire under all the boilers must be extinguished, and for such a battery nothing else can be done than in the case of a single boiler when a fusible plug melts out.

Question 241—If, in a battery of disconnectable boilers a fusible plug melts out of one, how are you required to attend to the battery?

Answer—We must close the steam valve in the branch steam pipe of the defected boiler first, and then shut off the water supply for this boiler also. The other boilers of the battery can be

kept in operation because the steam that escapes from the open plug extinguishes the fire only under the defected boiler. The steam valve must be shut first, otherwise the other boilers would commence foaming and the water supply pipe of the defected boiler must be closed, otherwise it would receive all the water, and the other boilers would be without a supply thereof.

Question 242—What apparatuses are used for feeding a boiler?

Answer—The tank or hydrant, the pump, the injector or the inspirator.

Question 243—What is understood by feeding a boiler by means of a tank or hydrant?

Answer—Water standing above the level upon which a boiler is situated, can feed it by means of tubes if brought in communication therewith, provided the water column that is represented in height, overbalances, by its pressure, the pressure of the boiler, and the friction caused by the communicating tubes.

Question 244—How much higher must the water stand of a hydrant or tank be than the water stand in the boiler when used for water feeding while the boiler stands under 60 lbs. overpressure?

Answer—Provided we have a tank connected to a boiler, and have in the connecting pipe a stop-cock near the bottom of the boiler, and there is no water in the boiler which is closed airtight, we would have in the boiler air of one atmosphere's pressure. If we should fill the tank up with water, so that it would stand in the communicating pipe to a height of 33.885 feet, no water would enter the boiler if we should now open the stop-cock, because air of one atmospheric pressure in the boiler would balance itself with the pressure of a water column of the height of 33.885 feet. We see from this, that only a surplus of water, that is, if the pipe were filled higher, can enter the boiler, and even not all of that because the air in the boiler would be compressed by the entrance of water, the greater water column, in excess of 33.885 would thus be held in balance. This shows, that for the purpose of calculating the height of a water column, by which we may feed a boiler, we must take into consideration the real pressure of the boiler and remember water pressure is balanced by real pressure, and only the surplus over that water pressure can enter the boiler. If we recollect, that when we have 60 lbs. over-pressure in the boiler, that this really represents 74.7 of a pound of real pressure, then we are able to represent this pressure which is given in pounds,

in atmospheres, by dividing the 74.7 by 14.7, and if we multiply this quotient by 33.885, we get the water column that must stand above the level of the water in the boiler in order to balance the boiler pressure by:

$$\frac{74.7 \times 33.885}{14.7} = 172.191 \text{ feet.}$$

We must add to this an extra amount that can be used as feed water. We express this incorrectly in the customary way, as the atmospheric pressure is considered as 15 lbs. and the water column that represents an atmosphere's pressure as 34 feet; by considering the real pressure as 75 lbs. we get this formula:

$$\frac{75 \times 34}{15} = 170 \text{ feet.}$$

FIG. 96.

Question 245—How must the water supply pipe of a boiler, that acts as the communicating pipe of a tank, be arranged?

Answer—The water supply pipe must not only have a check valve, and between it and the boiler a globe valve or stop-cock, but it must have at each side of the check-valve a stop-cock or globe valve, so that the check-valve may be reground or renewed without losing water out of the tank or boiler. The check-valve in a supply pipe is a necessity, as the passage must be open during the feeding, and without a check-valve the tank pressure would be over-balanced by the boiler pressure and the water would be driven out of the boiler and into the tank. While the boiler is operating, the stop-cock between the check valve and boiler always stays open, while the stop-cock between check valve and the tank or hydrant is open only when water is needed, and must be closed as soon as the boiler is sufficiently supplied, otherwise the boiler might be filled too high. The engineer is able, by cramping this cock, to feed continuously, provided the pressure of the hydrant is constant.

Question 246—What arrangement must be made, so that the engineer can control the water-stand in the tank or pressure in the hydrant with ease?

Answer—We place a steam-gauge on the communication pipe between the hydrant or tank, and the boiler, at the height of the water level in the boiler. When this indicates a little higher pressure than is indicated by the steam gauge on the boiler, we have water on hand to supply the boiler. Figure 96, on page 119, shows the arrangement of a tank to a boiler. A is the tank, B the steam gauge in the communication pipe *a,* and C the check valve, while *d*-1 and *d*-2 represents the two stop-cocks or globe valves. E is the boiler and F the steam-gauge on same.

PUMPS

Question 247—What do we understand by a pump?

Answer—A pump is an apparatus so constructed, that when in order, and a continuous motion is effected therein, it will lift water from a depth to a certain comparative height, under assistance of the atmospheric air pressure, without using extraneous power for any purpose other than to overcome the friction of the apparatus.

Question 248—What constitutes a pump?

Answer—A pump requires a barrel, which has two openings, closed by valves, and when so closed, the pump barrel must be air-tight. The one valve must open towards the inside,

consequently into the pump chamber, and the other valve towards the outside of the barrel. A contrivance must be brought in motion in the barrel alternating, for the purpose of enlarging and diminishing reciprocally the room of the pump chamber.

Question 249—What contrivance is generally used in a pump to enlarge or diminish the room of the pump chamber?

Answer—Generally, we use either a plunger or a piston for this purpose in steam engineering.

Question 250—What is the difference between a plunger and a piston?

Answer—Both are movable rods, air-tight in a pump barrel. The plunger rod is moved in a stationary packing, while the piston has a packing fastened to itself which moves with it. Figure

FIG. 97. FIG. 98.

97 shows a plunger rod with its packing. Figure 98 shows a piston rod with its packing, each acting in a barrel. In both figures P represents the packing and Figure 97 shows this packing stationary in the stuffing box S.

Question 251—How high can atmospheric air lift water in a pump which is kept in reasonably good order?

Answer—If a pump barrel would remain perfectly air-tight at all times, and the valves were always air-tight in their seats, and if it were impossible for dirt to get between the valves and their seats, and neither valve or seat would, by constant wear and tear, wear out, and the packing would remain perfectly air-tight, such a pump would be perpetually capable of raising water to the height of 33.885 feet. But with permanent use of the pump, the wear and tear will not permit such continuity of perfect tight-fitting all around, and, therefore, we must be satisfied if an engineer is able to keep his pump in such order that the atmospheric air can accomplish two-thirds of that effect; that is, that the pump will lift water to a height of 22 to 24 feet on an average.

Question 252—How do you describe the two pumps illustrated in Figures 99 and 100, and how does the action of the air therein facilitate the lifting of water?

Answer—In both figures the pump barrel is indicated by B, and the valve that opens into the pump chamber is indicated by R, and is called the receiving valve of the pump. The valve that opens towards the outside of the barrel is called the discharge valve and is indicated by D. As an escape for the water from the pump, a spout is used, which is indicated by an S. In

FIG. 99.

FIG. 100.

Figure 99 we have a plunger in action, which is indicated by A. In Figure 100, we have a piston in action, which is indicated by B. The packing of the plunger is placed in the stuffing box H, and the packing of the piston B, is indicated by *b*. In Fig. 100, where the piston is in action, the discharge valve D is placed on an opening in the piston B. The packing of the plunger is marked with *a*, and the packing of the piston is marked with *b*. When piston or plunger in one of these pumps that are called common pumps, is raised up, the room of the pump chamber is enlarged and the atmospheric air pressure at once forces all that is between itself and the evacuated room as far as it can therein, especially water which it keeps in balance to the height of 33.885 feet, and, as before explained, to a slight additional height if no air can enter at the same time through the wall of the pump barrel, or through an untight valve or packing into said evacuated room. The motion

SECTIONAL VIEW OF PISTON OF FIG. 100.

of the piston or plunger may be only a small one, and on account of this only, that little evacuated room can be filled with water. When the plunger or piston makes the return, or opposite motion, the air that is in the pump barrel is driven out through the discharge valve, while the water therein is retained by the receiving valve, and after a number of repetitions of this up and down stroke, the water lifted into the barrel by the atmospheric air-pressure, passes through the discharge valve and out at the spout.

Question 253—The pump barrels in the pumps, illustrated in Figures 99 and 100, are very large and clumsy; is it not possible to construct such pumps, and at the same time make a reducton in their size and weight?

Answer—In Figures 101 and 102, on page 124, we have a plunger and a piston pump, with small barrels, and these barrels do not

extend into the water, but instead, pipes that extend are joined to them, Fig. 101 is the piston pump and Fig. 102 the plunger pump. The action of these pumps is really the same as that of those heretofore described. The pipe that is attached to the barrel is called the receiving pipe, and is marked L in the illustration. These mechanisms are known as lifting pumps.

FIG. 101. FIG. 102.

Question 254—What must we do when compelled to get water by means of a pump, out of a depth, or force it to a height greater than about 22 feet?

Answer—We insert a pump barrel into the water, and instead of a spout, place a vertical pipe on it. This variety of pumps are called force pumps, and the pipe used is called the discharge pipe. Figure 103 represents such a pump. The water enters in this barrel and fills it entirely by the upward stroke of the pump, even if it is extending partly out of the water. By the

FIG. 103.

FIG. 104.

downstroke of the pump we have to use our power to raise the water upwards, and discharge it through the discharge pipe.

Question 255—Can we not economize power and get assistance from the atmospheric air to first lift water into a certain height, so that we will not be compelled to carry its whole weight to the required height?

Answer—Yes, we can. When we use the pump illustrated in Figure 104, in this construction, we add to the pump barrel a receiving and discharge pipe, and call this kind of pump a lifting and force pump combined. In this construction the atmospheric air pressure lifts the water into the pump barrel, from a certain depth, and we have to use our power only to force the water through the discharge pipe.

Question 256—For what are force pumps, or lifting and force pumps, combined, used in addition to raising water out of a great depth?

Answer—These pumps are used, in addition to the purposes mentioned, for filling up tanks and feeding boilers. For both of these purposes, we must use extra power; for a tank, to balance the water pressure; for a boiler, to balance the boiler pressure.

Question 257—Is it quite immaterial in what position the valves lie with reference to each other, that is, the receiving and the discharge valve of a pump?

Answer—In the illustrations of pumps which we have seen before all of the receiving valves are lying lower than the discharge valve. The Figure 105 shows a pump in which the receiving valve lies in the same position as the discharge valve. Figure 106 shows a pump in which the discharge valve lies lower than the receiving valve. It is easy to see from the illustra-

FIG. 105. FIG. 106.

tions that both pumps are bound to act, and it is only necessary to remember that the valves must fit tightly in their seats, that the receiving valve must open towards the chamber, while the discharge valve must open towards the outside of the barrel, and that both, barrel and packings, are tight.

Question 258—Does it not tire a man more if he uses his power irregularly; for instance, when he must operate the force pump, which by the up-stroke only, the friction must be overcome, while by the down-stroke not only the friction, but also the counteraction of the water pressure and boiler pressure must be overcome?

Answer—Irregular work not only makes a man tired, but it wears a machine more on those places where a great power is used than on those places where a small power is required. It is therefore preferable for man and machine that the work should be as regular as possible.

Question 259—How is it possible to overcome these irregularities in pumps?

Answer—When we join two single pumps together in such a way that an alternate motion takes place in them, that means, while one pump makes the up-stroke, the other makes the down-stroke, we use for each stroke the same power. A pump, thus constructed, is called a double-acting pump.

Question 260—Is it necessary that a pump barrel should always occupy a vertical position?

Answer—A pump barrel may quite as well lie horizontally; it may be a single or a double-acting pump; that don't matter. Fig-

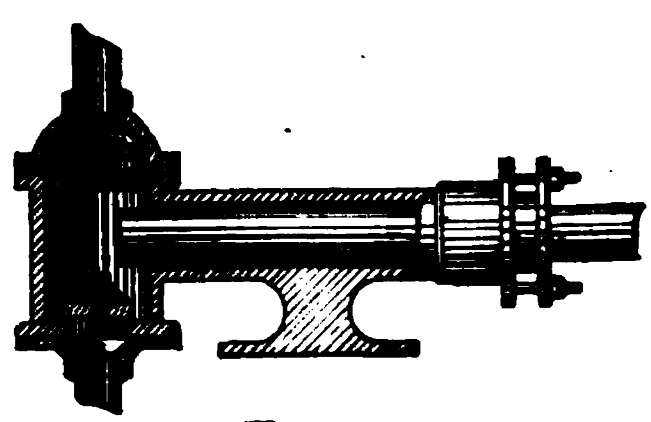


FIG. 107.

ure 107 shows a single-acting plunger pump in a horizontal position. The strokes of such a pump are called in-stroke and out-stroke.

Question 261—What conditions must be complied with in the construction of a double-acting pump?

Answer —A double-acting pump must have two pump chambers, in each of which a contrivance must operate for enlarging or diminishing the room, alternate motions, that is in reciprocal

directions; each pump chamber must contain a pair of valves, a receiving and discharge valve; the pump chamber must be enclosed air-tight; the valves must fit tightly to their seats; only one receiving and one discharge pipe are required, but each must be arranged to a compartment in which the respective valves close up the pump chamber; the two pump chambers must be air-tight, separated from each other like the receiving and the discharge compartments, and neither one or the other of the latter should communicate with the pump chambers, except through their respective valves.

FIG. 108.

FIG. 109.

Question 262—In Figure 108 we see a double-acting piston pump; are you able to tell us whether this pump is in order or not, and if it is in order, which valves will open if the piston is moving in the direction the arrows point?

Answer—No valve can open when the pump is in the position shown by Figure 108, because the partition between the two pump chambers is missing. If this partition is replaced as Figure 109 shows at P, then the right-hand receiving-valve and the left-hand discharge-valve will open when the piston moves in the direction indicated by the arrows. In these illustrations, as well as in the following, the receiving-valves are marked with R; that to the left hand side with R1, and the right hand side with R2. The left hand discharge-valve is marked with D1, and the right hand one with D2. The pump chamber at the left hand side with C1, and that to the right-hand side with C2. The receiving compartment is marked *r*, and the discharge compartment *d*.

Question 263—In Figure 110 we see a double-acting plunger pump; can this pump act, and if so, then when it is acting, which valve will open when the plungers are moving in the direction indicated by the arrows?

Answer—This pump cannot act, because the two pump chambers, C1 and C2 are in communication at P, but as soon as the leakage is stopped as Figure 111 shows, the left hand receiving valve R1, and the right hand discharge valve D2, will open.

FIG. 110. FIG. 111.

Question 264—Figure 112 shows us a double-acting pump, which has only one barrel, but the piston divides this barrel into two pump chambers; and only one contrivance, a piston, acts in both chambers, in the one for diminishing, and the other for enlarging its room, alternately; can this pump act, and if so, which valves will open when the piston moves in the direction indicated by the arrow?

Answer—This pump is bound to act as soon as the piston fits air-tight in the bore of the barrel and the left hand receiving valve and the right hand discharge valve are bound to open when the motion indicated takes place.

Question 265—If a pump is constructed after the shape shown in Figure 113, the names of the single parts are indicated by the same letters; can this pump act, and if so, which valve will open while the piston is moving in the direction indicated by the arrow?

Answer—This pump cannot act because the two pump chambers C1 and C2 are in communication; *r*, the receiving compartment forms a kind of an extra casing, into which the receiving pipe extends. We see a partition is necessary in this barrel

FIG. 113.

FIG. 114.

at P, as the Figures 114 and 115a show, to render the pump ready for action. When the piston moves in the direction indicated by the arrow, it will lift the left hand receiving valve R1, and, also, the right hand discharge valve D2.

FIG. 115 FIG. 115A.

Question 266—The pump, illustrated in Figure 116, requires something for completion; can you tell what is necessary to render it ready for action?

Answer—Figure 116 shows us a front elevation of the pump barrel with the cover of the valve case taken off. In the Figures 117 and 118 is shown the way the pump must be com-

FIG. 116.

FIG 117.—SECTION V-W

pleted. The Figure 117 shows a horizontal section in the direction of *v-w*, and Figure 118 shows a cross-section in the direction of *x-y*. In Figure 116 a separation of the pump

FIG. 118.—SECTION X-Y.

chamber is not shown. The valve chamber, which forms a part of the pump chambers, must be separated by P, and communications, N1 and N2, must be made so that the dis-

FIG. 119.

charge compartment and the receiving compartment can be brought in communication with both pump chambers by their respective valves.

Question 267—Can you explain a double-acting pump in which the two pairs of valves lie in the same plane?

Answer—Figure 119 shows us the top view of such a pump, with the cover taken off; *r* is the receiving pipe, *d* the discharge pipe, R1 and R2 the receiving valves and D1 and D2 the discharge valves. N1 and N2 show communications to pump chamber C1 and C2. P shows the partition which separates the pump chambers. Figure 120 is a longitudinal section in the direction of *y-z*. Figure 120a is a longitudinal section in the direction of *u-v*. Figure 120b is a longitudinal section in the direction of *w-x*. Figure 121 is a cross-section in the direction of *r-s*.

FIG. 120—SECTION Y-Z

FIG. 120A—SECTION U-V.

FIG. 120B.—SECTION W-X.

Question 268—Can a double-action pump be constructed so that the receiving valves will lie higher than the discharge valves?

Answer—Figures 122, 122a, 122b and 122c show us such a construction. You will notice that pump chamber, receiving and discharge chambers are separated by partitions. Figure 122 shows a cross-section; the valve to the left is a receiving valve, which lies much higher than the discharge valve to the right. Figure 122a is a longitudinal section, in the direction

FIG. 121.—SECTION R-S.

FIG. 122.—SECTION S-W.

of *x-z,* showing the receiving valves and the partition. Figure 122b is a longitudinal section in the direction of *u-v,* showing the discharge valves and partition. Figure 122c shows this pump complete, the white lines indicating the location of valves and partitions.

FIG. 122A.—SECTION X-Z.

FIG. 122B.—SECTION U-V.

FIG 122c

Question 269—What extra parts may you find connected to single action pumps, as well as to double-action pumps?

Answer—Pet-cocks, drain-cocks and air chambers.

Question 270—What is a pet-cock, where is it placed on a pump, and what is the purpose thereof?

Answer—A pet-cock is a small cock which is placed in the highest part of a pump chamber, and is used for the purpose of discharging air therefrom.

Question 271—How is air collected in a pump chamber, and what harm does it there?

Answer—If the packing in the stuffing box of a plunger pump, or the packing of the piston of a piston pump, or the pump barrel itself commences to leak, air enters at every up or out stroke through this leakage, and at the same time that water enters through the receiving valve. The pump chamber does not receive the full amount of water that it would if such a defect did not exist. Now, if this air cannot be discharged with the water into the boiler or tank, because it cannot be brought to a pressure equalling the counter-action, it will not permit the atmospheric air-pressure to bring water into the pump barrel. We say, then, that the pump is air-bound, and cannot deliver water to a boiler or a tank. The air must be discharged out of the pump barrel first before the pump is able to act again for that purpose. This can be done if, at the down and up-stroke, the pet-cock is opened and closed at the reverse stroke.

Question 272—What is a drain-cock, where is it placed, and for what purpose is it used?

Answer—A drain-cock is placed at the bottom of the pump chamber, so that the water may be driven out of the pump chamber when the piston arrives at the end of its stroke. It is also placed in the water supply pipe, at the lowest part thereof, to drain it before taking off the cap of the check valve and taking the latter out of its seat, self-understood, after the stop-cock or globe valve is closed to secure the water in the boiler.

Question 273—What is an air-chamber, where is it attached to a pump, and for what purpose is it placed there?

Answer—The air-chamber has the shape of a bottle, with a long neck. It is placed upside down, consequently with its neck connected to the discharge part of the pump. It contains air before the pump is in action, and keeps it in full volume by receiving the water in the chamber. The air in the air-chamber is, consequently, not affected; but by the discharge of the water from the pump chamber, the air must be compressed in its chamber so that its pressure will equal the counteracting pressure of the tank or boiler. The consequence is, that by reciprocating strokes, the action of the valves against their seats will not take place with a hard clicking, inasmuch as the air in its chamber forms a cushion. The valves and their seats are, consequently, not injured so much as when no air-chamber is on the pump, and mechanical impurities lying in the water, get between the valve and its seat.

Question 274—Why do you provide an air-chamber with a small and long neck?

Answer—It is done for the purpose of preventing, as far as possible, the passing water from absorbing the air in the air-chamber, for running water absorbs air, and the larger the surface of water exposed to air, the more of it will be absorbed, and without air, the air chamber would be useless. Therefore, the air-chamber must be inspected, from time to time, and new air brought into it, a drain-cock opened in the discharge compartment, or an air-cock opened in the air-chamber, while the pump is in motion, will discharge water and let air enter.

Question 275—If we have a single-acting pump which discharges the water out of the spout, what part of it may be out of order, and the pump still deliver water?

Answer—None of the parts which constitute the pump can be entirely out of order without preventing it from delivering water.

Question 276—If we have a lifting and a force-pump combined, that will feed either a tank or a boiler, what part thereof may be out of order, without impairing the pump, so as to prevent it from delivering water to the tank or the boiler?

Answer—Provided we have a check-valve between the pump and the tank or boiler, the discharge valve may be out of order, and the tank or boiler will receive water, even though the discharge valve is out of order, because the check-valve will act as a substitute of the discharge valve in a single-acting pump.

Question 277—If a lifting and a force-pump combined, is joined to a boiler, what does the pet-cock, joined to the pump chambers, show, when the boiler receives water, and what does it show when it does not receive water?

Answer—When the pet-cock is opened while the pump is in motion, and shows an intermitting stream of water, this proves that the boiler receives water, because the pet-cock shows no water when the pump chamber receives the water, but otherwise when the pump chamber delivers it to the boiler. If the pet-cock shows no water at all, or if it shows a constant stream, in both of these cases, the boiler does not receive water. The same will be shown by the pet-cock of a pump used to deliver water to a tank, provided that a check-valve is placed between the discharge valve and the tank. When the pet-cock shows a constant stream of water, both the check-valve and the discharge valve are out of order, the boiler or tank pressure drives the water out of the pet-cock, the boiler pressure acts on the receiving valve, preventing the smaller, that is the atmospheric air-pressure, from lifting water into the pump chamber. And when no water appears from the pet-cock, while the pump is in motion, either the pump is air-bound or some part necessary for receiving water out of order.

Question 278—What may get out of order in the receiving part of a pump?

Answer—1. The receiving pipe may not extend into the water. 2. The receiving pipe may be clogged. 3. The receiving pipe may be bursted above the level of the water that is to be lifted. 4. The receiving valve may be out of order.

Question 279—What do you understand by a valve on a pump being out of order?

Answer—A valve may leak a little, and then it is not acting as it should, but the pump may not, on that account, get out of order entirely and may deliver only a part of the water which it should lift, but if such a leak is a considerable one, it is as

though the valves were suspended in the water, and allowing almost a free passage, it is quite as useless as if no valve were there.

Question 280—What does a pet-cock show when the receiving-pipe does not stand below the level of the water to be lifted?

Answer—If a piston or a plunger of a pump makes an up or an out-stroke when the pet-cock is opened, and the receiving pipe does not reach the water, air can enter as well through the pet-cock as through the receiving valve. But if the opposite stroke is made, all the air must exhaust through the pet-cock. Consequently, a piece of thin paper, held about half the height of the opening in the pet-cock, will make a slight motion towards it when an up or out-stroke is made, and will be moved more violently away from it by the opposite stroke.

Question 281—What will a pet-cock on a receiving and force pump combined show when opened by an up or down stroke, when the receiving pipe leaks above the water level?

Answer—It shows as the above, alternately, a light inlet, and a strong outlet of air.

Question 282—How can an engineer ascertain whether the receiving pipe of such a pump leaks above the water level, or does not extend into the water?

Answer—A look into the well will enable him to see, at once, whether or not the pipe stands above the water level, and if it does not, he may be sure that it is leaking above the water level, if the pet-cock acts as explained above.

Question 283—If the receiving pipe is clogged in a lifting and force pump combined, what will the pet-cock show when opened at both strokes?

Answer—When such is the case, neither water nor air can enter through the receiving pipe. Air can enter the pet-cock only by the up and out-stroke, consequently, when the paper is held in the position described above, it must indicate a strong inlet and an equally strong outlet of air at these strokes.

Question 284—What does the pet-cock show when opened while a lifting and force-pump combined is in motion and the receiving valve is out of order?

Answer—As has been explained already, a light leakage of the receiving valve affects only a part of the water it would discharge if no leakage were there at all. But we say that the receiving valve is out of order when no water can be discharged by the pump, and if the pet-cock shows no water, either by the one or the other stroke, the valve is leaking seriously, and is, consequently, about as good as if no receiving valve were in existence. Now, if this is the case, the

pump barrel will be filled with water by the up or out-stroke, because the apparatus acts like a syringe; but the same water that has been lifted will fall back into the well at the down or in-stroke, as well as at the up or out-stroke, and if the pet-cock is opened and a piece of paper is held as aforesaid, immediately, it will be violently drawn against the opening thereof, pending a few double strokes, because all the water that has been in the pump and the receiving pipe, must fall back into the well, and air follows through the pet-cock.

Question 285—Is it a necessity to have a check-valve in the water supply pipe of a boiler that is fed by a pump?

Answer—As long as the pump is in motion it will feed the boiler, even though the check-valve may be out of order, because the discharge valve of the pump will permit the delivery of water from the pump to the boiler; but as soon as the check valve on a pump gets out of order, and the pump is brought to rest, it will get warm, and may be spoiled, so that it cannot deliver any water to the boiler when it is started again.

Question 286—What may spoil a pump while it is at rest, if the check-valve of the boiler is missing, or out of order?

Answer—As long as the pump is feeding water, neither it nor the supply pipe can possess a higher temperature than the water that is being fed, but as soon as the pump comes to rest, the feed water may be heated down to it, because the supply-pipe forms a part of the boiler when the check-valve is not performing its duty; therefore, when heat is applied to the water in the boiler continuously, and no new water is added, hot water extends down to the pump, its barrel gets warm, and soon it is steam-bound.

Question 287—What do you understand by a steam-bound pump, and how may a pump so bound be spoiled?

Answer—When a pump gets hot, it is bound to make the water in its barrel hot also, and inasmuch as water evaporates under a vacuum at 35 degrees Celsius, the temperature influences the height to which it may be lifted. The rule is, that atmospheric air lifts water a height of 33.885 feet, if the apparatus by which it is to be lifted is perfectly air-tight, and the water carries a temperature of zero degrees. And, as water increases in warmth, the height to which it can be lifted, or pumped, decreases. We have stated before, that with pumps that are kept in average good order, water of zero degrees can be brought to a height of 22 to 24 feet, but the warmer the water gets the more this height is reduced, because we fill up a vacated space immediately with vapor, that is, steam, which is due to the temperature of the water. Consequently,

we receive inside of the barrel a pressure that is acting against the atmospheric air pressure, and, therefore, the height to which the water may be lifted must correspond with the difference between these two pressures whenever a pump barrel, and, consequently, the water in it reaches a temperature of 100 degrees, this brings the water or steam, which is created near, or equal to the atmospheric air pressure, and the lifting of water by the atmospheric air pressure is, therefore, rendered an impossibility. And if we are unable to lift water into the pump barrel, the pump will discharge no water into the boiler, and, therefore, it is spoiled for the purpose of feeding the boiler, until it has cooled down again and the packing that had become loose from the heat is renewed. But not only the packing is spoiled, but the surface of the pump likewise, by a packing that has become hard and brittle, producing grooves that may require an entire overhauling of the apparatus before it can be used again with good results.

Question 288—Under what circumstances does a draw-back occur in feeding a boiler with a single force pump, when the check valve in the water supply pipe is in order, but the discharge valve is out of order?

Answer—We will have a draw-back then, only when we have added to this pump an air chamber.

Question 289—What draw-back will we experience if an air chamber is added to a single acting force pump, and the discharge valve thereof is out of order?

Answer—The air chamber of a pump must be filled with air in order that it may act as a cushion, and this air, at the start, is of one atmosphere's pressure. But by the delivery of water to the boiler, this air in the air-chamber is compressed and is bound to balance the boiler pressure before water can be delivered to the boiler. If now the discharge valve gets out of order, and an up or an out-stroke of the pump takes place, the air so compressed in the air chamber expands and fills up the pump chamber, not allowing the atmospheric air pressure to lift water into the chamber, except for such a space in the pump barrel, in which by enlarging the air in the pump chamber, the air in the air chamber would be diminished to less than one atmosphere's air pressure. The absence of the discharge valve, or the same being partly out of order would, consequently, not allow the discharge of the water from the pump in the amount and volume it was constructed for.

Question 290—For what amount of water must a pump be constructed?

Answer—It is impossible to prevent impurities from passing through a pump with the water, and if such impurities lie between the valve and its seat, by the reverse of a stroke a smaller amount of water would be discharged than if valve and seat fit tight together; besides this, at the reverse of a stroke during the time it takes a valve to find its seat again, a part of the water is falling back on account of the reversed motion, and the amount lifted is reduced as a result. The leakage in a pump, which can not be prevented entirely, must be taken into consideration also. We cannot estimate the result to be ordinarily obtained from a pump as greater than of seven-eighths of the sum of the area of a plunger or piston multiplied by the stroke will show by calculation.

Question 291—If a single acting pump with a plunger of one inch in diameter, and a stroke of 12 inches, makes 120 double strokes in a minute, how many cubic feet of water can it discharge into a boiler in an hour's time, if kept in reasonably good order?

Answer—The amount of water that should be discharged into the boiler by every double stroke must be found by multiplying the area of the plunger by the stroke. If we multiply this by the number of strokes per minute, that is, 120, and then multiply the result by 60, to get the amount of water that will result per hour in cubic inches, and then divide that by 1728, we would have the number of cubic feet of water which could be delivered by the pump in an hour's time, if we did not have to reduce it by seven-eighths, according to the circumstances explained. Therefore we get this formula:

$$\frac{1\times1\times11\times12\times120\times60\times7}{14\times1728\times8}=34.38 \text{ cubic feet.}$$

Question 292—If we have a double acting pump, the piston of which is 5 inches in diameter, and the stroke thereof is 12 inches, and the pump will make 60 single strokes per minute, how many cubic feet of water will be delivered to the boiler per hour?

Answer—We must multiply the area of the piston by the length of the stroke, then by the number of minutes per hour, and divide the result by 1728 to get the cubic feet, and we will get as a result the water that can be discharged per hour; when we consider only seven-eighths of that amount, on account of the drawbacks explained above, we get the formula:

$$\frac{5\times5\times11\times12\times60\times60\times7}{14\times1728\times8}=429.68 \text{ cubic feet per hour.}$$

Question 293—How long must the stroke of a plunger of a single acting pump be, if the area of the plunger is 3 square inches, and the pump must deliver, by every double stroke, 21 cubic inches of water?

Answer—We must construct the pump so that $^8/_7$ times 21 cubic inches of the room in the pump chamber will be vacated by every up or out-stroke of the plunger, and if we divide the product mentioned by the area of the plunger, we get as a result:

$$\frac{8 \times 21}{7 \times 3} = 8\text{-inch stroke.}$$

Question 294—If, in a double acting pump the discharge valve is absent from, or out of order in one of the chambers, what would be the consequence, if the check valve is in order, and what, if out of order?

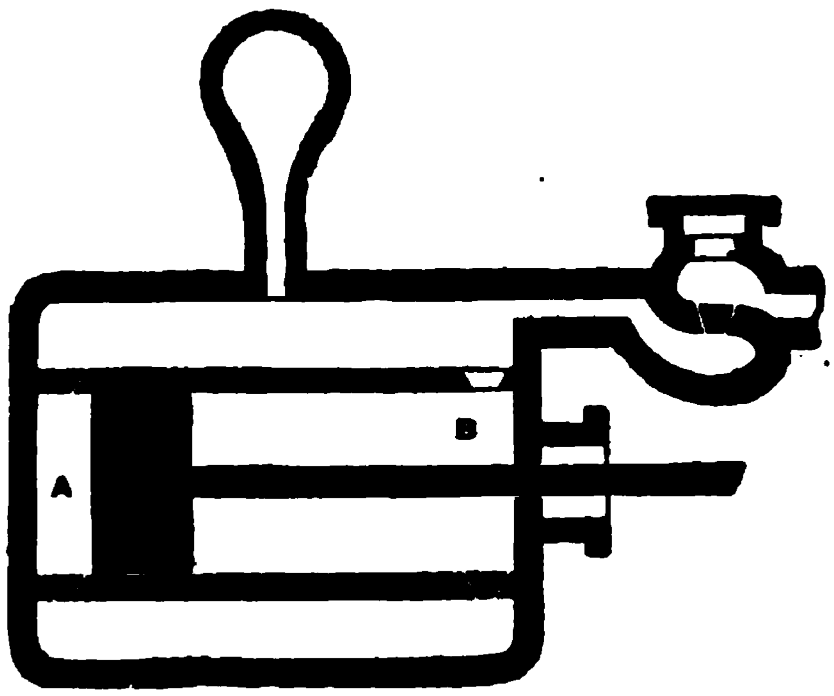


FIG. 123.

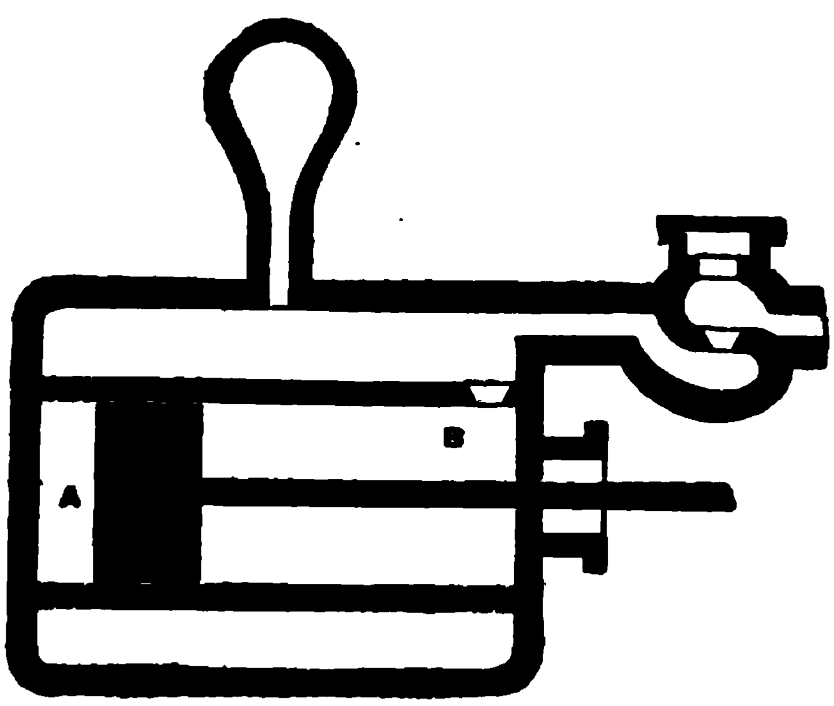


FIG. 124.

Answer—Figures 123 and 124 show the pump under these conditions. The valves that are out of order are not drawn,

either in these figures or those that relate to the following questions: When the piston is moving in the direction indicated by B, the water out of the pump chamber B, will be discharged into the boiler. It is quite immaterial whether the check valve is in order or not. At the same time the pump chamber A, will receive water. By the reverse stroke, whether the check-valve is in order or not, the water that lies in A will be discharged, not into the boiler, but into the

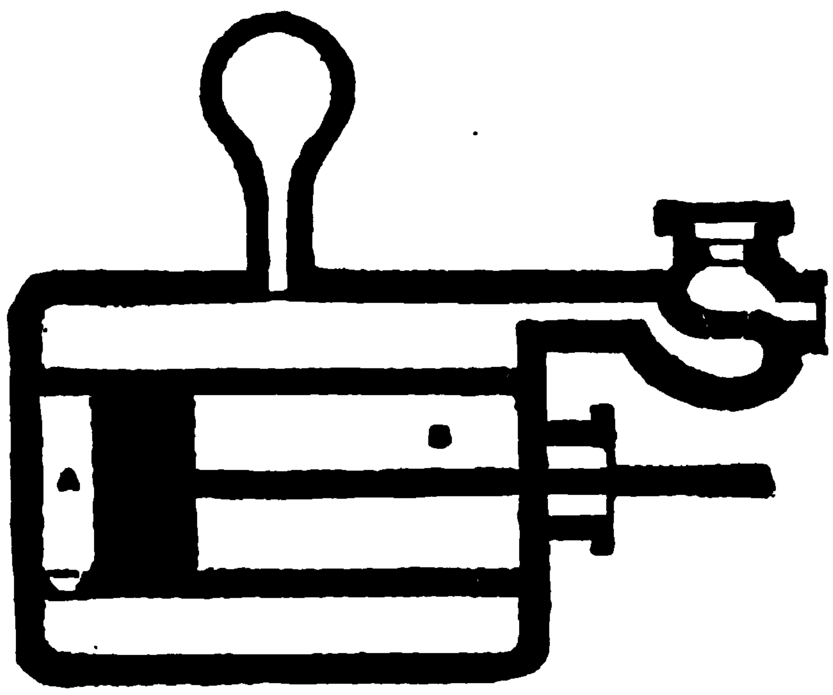


FIG. 125.

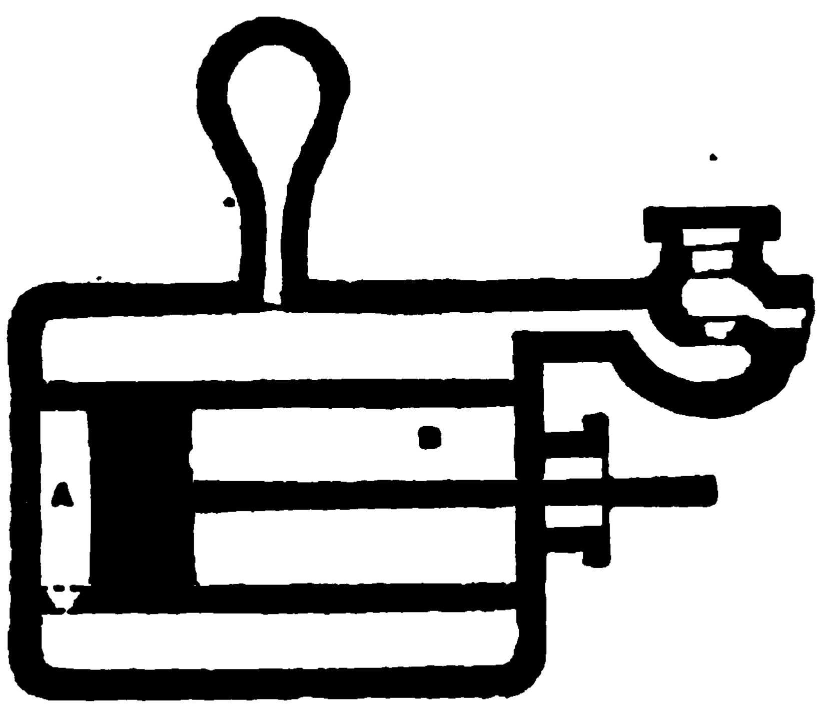


FIG. 126.

pump chamber B. This shows that when, in a double acting pump, the discharge valve in one of the chambers is out of order, the pump will deliver only half the amount of water for which it was constructed, and that out of the pump chamber that is defective, even though a discharge valve is missing here, an air chamber cannot influence the amount of water to be discharged by the pump, because the pump chamber A received the water, and it has a discharge valve.

Question 295—What would be the consequence, if in a double-acting pump a receiving valve is out of order, or missing from one of the pump chambers, when the check valve is in order, or out of order?

Answer—In Figures 125 and 126 these conditions are illustrated. The receiving valve that is out of order is not drawn, because

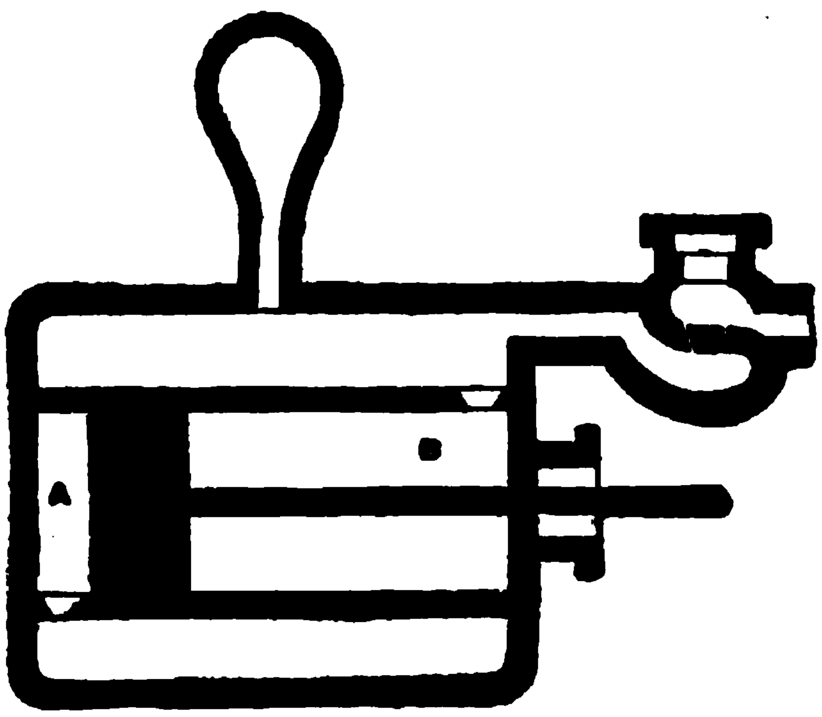


FIG. 127.

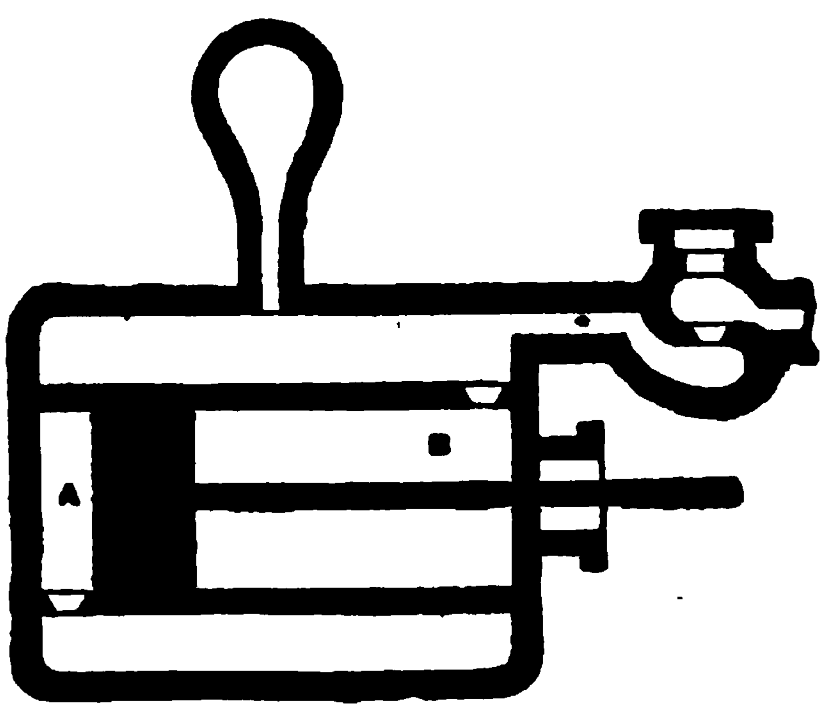


FIG. 128.

when a valve is out of order, it is as though it were not in existence. When the piston moves in the direction indicated by B, the pump chamber A will receive water, while the pump-chamber B will discharge the water it contains into the boiler. If the stroke should be reversed, the pump-chamber B will receive water and A would discharge it into the well, whether the check valve were in order or not. This proves that when a receiving valve is out of order in one of the chambers of a double-action pump it discharges one-half the amount of water for which it was constructed, and that

from the chamber in which both the receiving and the discharge valves are in order.

Question 296—When in the one chamber the receiving valve, and in the other the discharge valve is out of order in a double acting pump, what amount of water will it deliver when the check valve is out of order?

Answer—The valves that are out of order are not contained in illustrations for this question (Figures 127 and 128). The chamber B, from which the discharge valve is missing can deliver water to the boiler only while the check-valve is in

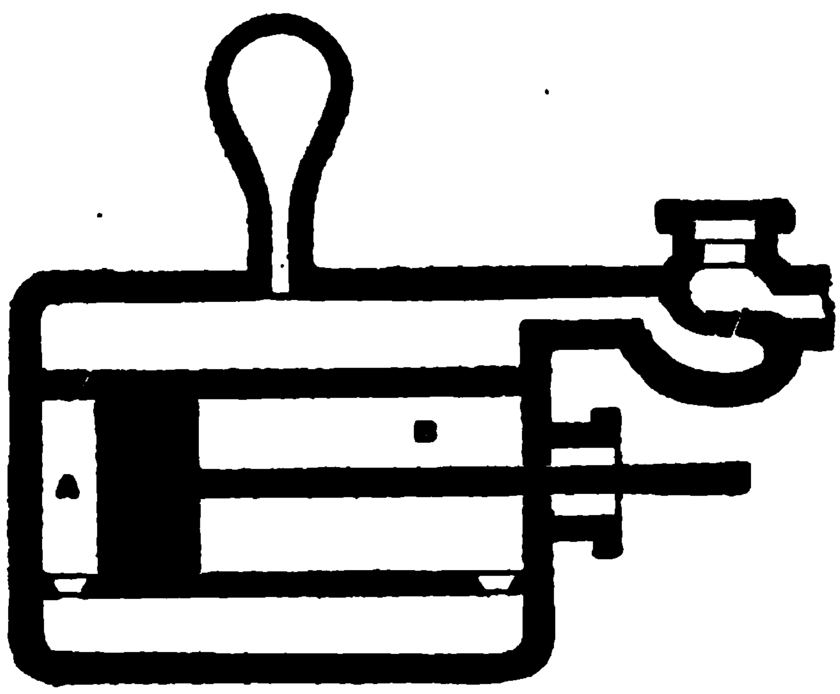


FIG. 129.

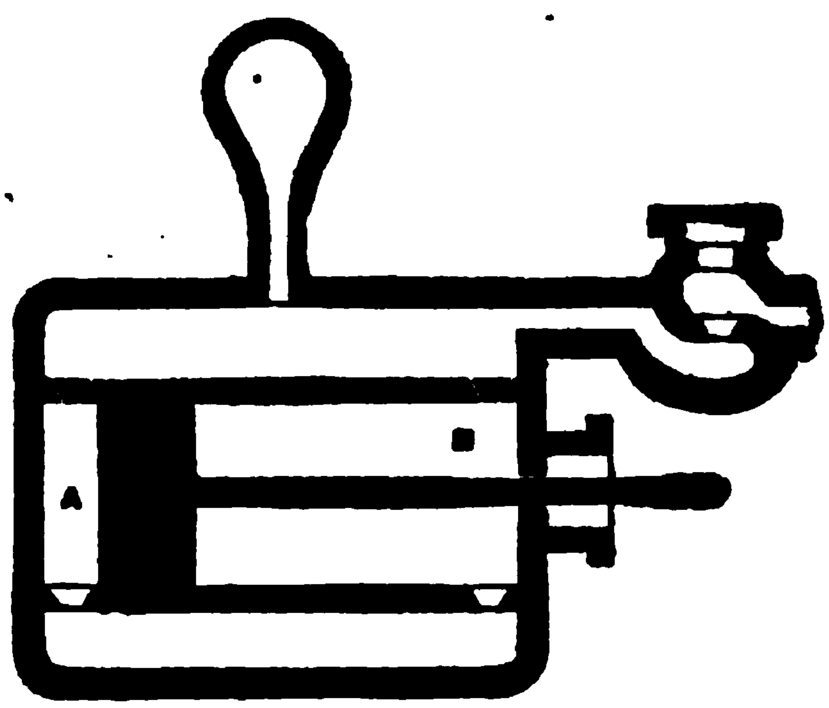


FIG. 130.

order, and only half the amount for which it was constructed, when the pump has no air chamber; but as soon as such is the case it will influence the discharge, and only a part of the half amount can be delivered to the boiler; and as soon as the check-valve is out of order, no water at all will be discharged into the boiler.

Question 297—What would be the effect, if in a double acting pump, the receiving valves in both chambers were missing, in case the check-valve is in or out of order?

Answer—Figures 129 and 130 illustrate the condition of a pump in both of these cases. It cannot deliver water to the boiler, because, although both chambers can receive water, it cannot be discharged into the boiler, and must, therefore, be turned back into the well. The check valve has no influence thereupon.

Question 298—When in a double acting pump, the discharge valve in both chambers gets out of order, what result will the pump give, when either the check-valve is in order, or out of order?

Answer—Figures 131 and 132 illustrate the question well; the valves being out of order, are not contained in the drawings; as the stroke goes in one or the other direction, the contents of the one pump chamber are brought over into the other. It

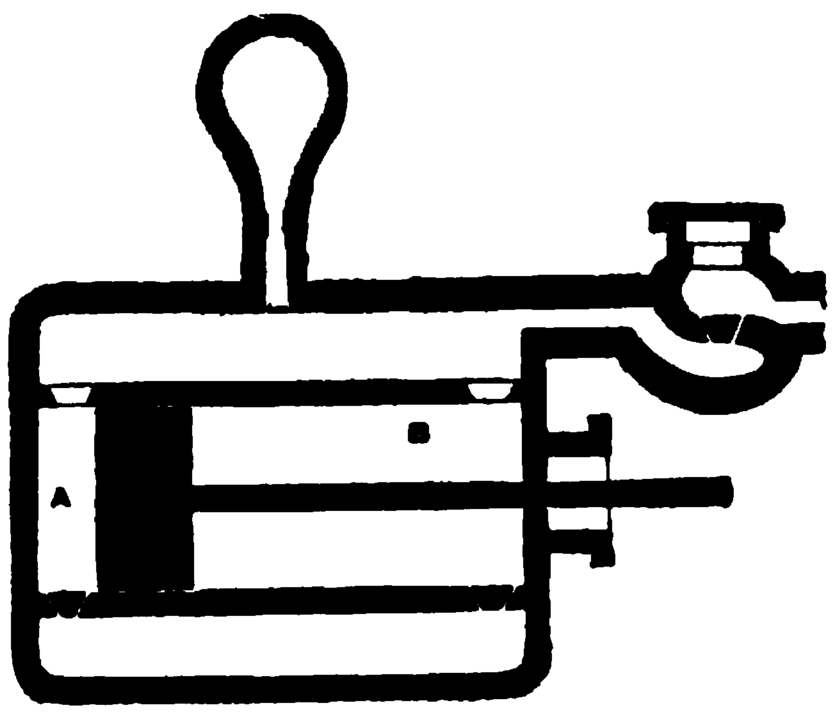


FIG. 131.

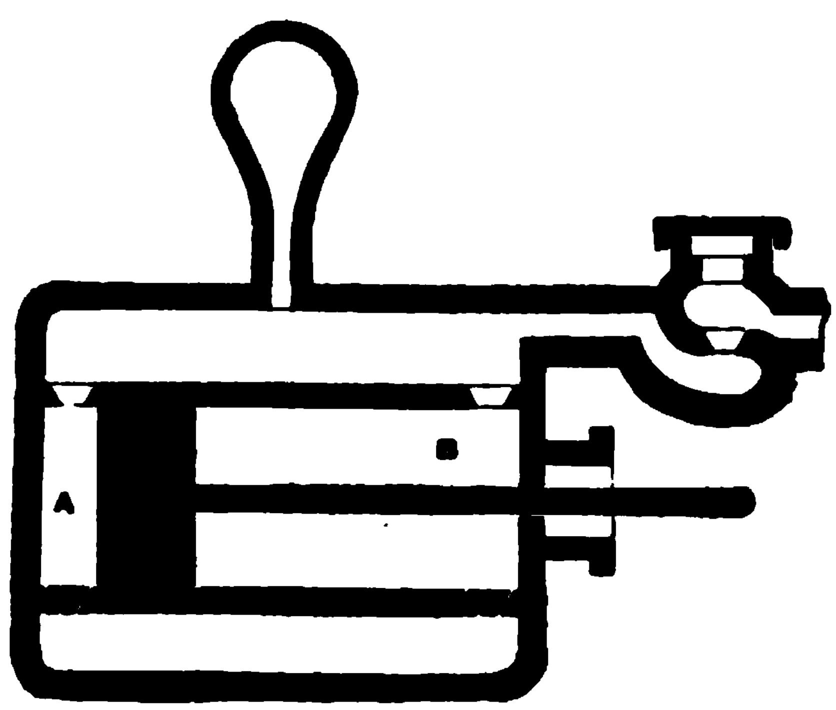


FIG. 132.

is quite immaterial whether the check-valve is in order or not. The pump, in such a condition cannot deliver water to the boiler, and we call the action that takes place in it "churning."

Question 299—If in a double acting pump the valves are in order in only one pump chamber, and in the other they are missing, or out of order, what result will the pump give, either when the check valve is in order, or out of order?

Answer—Figures 133 and 134 illustrate the question. The valves being out of order do not appear in the drawing. This pump can by no means deliver water to the boiler, even though the

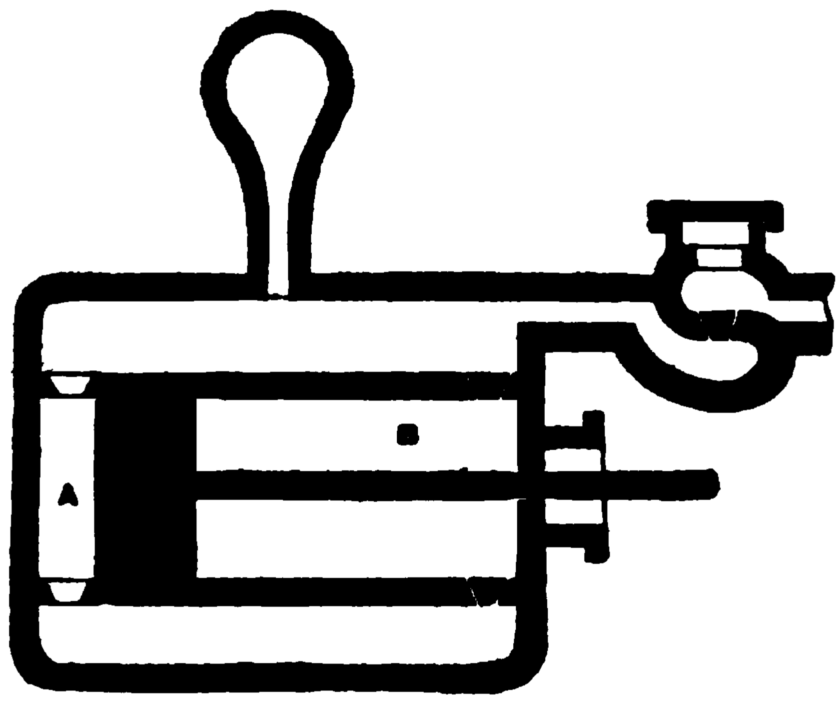


FIG. 133.

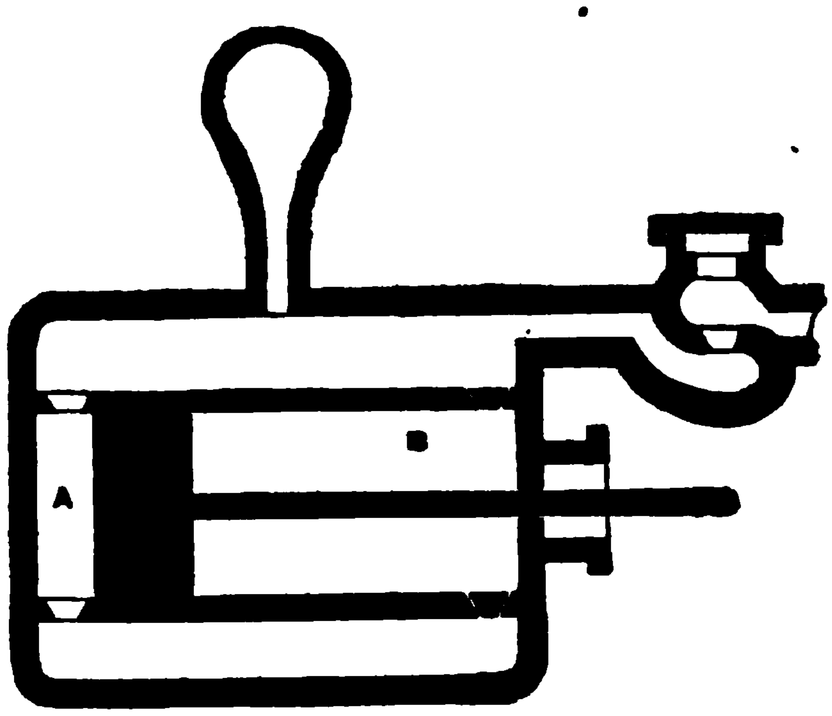


FIG. 134.

check valve is in order, and when the check valve gets out of order, the boiler is in danger, because the water in it will be driven by the steam pressure through the pump chamber in which the valves are out of order and into the well.

Question 300—Must a pump be placed in a certain position, when it is not in motion, but in connection with a tank or hydrant, for the purpose of filling a boiler, which stands without steam pressure?

Answer—All that is required is to set the boiler in communication with the atmospheric air, either by opening the third gauge cock, the safety valve, or a plug on top of it; the pump piston or plunger may stand in any position, so it does not hinder the passage of water, and open all valves, receiving, discharge and check valves, in the direction of the boiler.

Question 301—Does it take more power to start the stroke of a pump than is required during the stroke?

Answer—It is a well known fact that, to start a motion of a weight, a greater power is required than during the time that the weight is kept in motion. It may require the power of several men to start a loaded wagon, while one man may keep it in motion, so we must conclude that, to start the stroke of a pump also a greater power is required than during the stroke. And, especially, the power necessary to start the stroke must be increased to lift the valve. The top surface of the valve is larger than its bottom surface. For instance, we have a valve that has on its top surface an area of four square inches, and the boiler pressure that acts upon it is 100 lbs. per square inch, while the bottom surface of the valve is only three square inches; then we have resting on the top of the valve pressure of $4 \times 100 = 400$ lbs., and this pressure must be balanced by a power acting against 3 square inches. We need, therefore, a power on every inch of the bottom surface of the valve, equal to

$$\frac{4 \times 100}{3} = 113\tfrac{1}{3} \text{ lbs.}$$

When the valve is once lifted, and suspended in the liquid, only its weight, which is small, must be balanced extra.

Question 302—How can a double acting pump be arranged so that at every point of its motion a real equal pressure must be used?

Answer—The power necessary to keep a double acting pump in motion is the same during every stroke, but a greater power is required for the start of each stroke. To have regular and equal power ready at every moment, we apply to a pump a shaft with a fly-wheel, and to this gear the power, and by means of a crank, or eccentric, transfer it for the purpose of setting plunger or piston in motion.

Question 303—What is a fly-wheel, and how can we equalize, by means of it, the power on machinery which requires an irregular application of power during its motion?

Answer—A fly-wheel is a wheel the greatest weight of which is its circumference. For instance, we have a wheel the circumference of which weighs 100 pounds, and which is 7 feet in diameter, and we turn this wheel around once in a second, we have:

$$\frac{7 \times 22 \times 100}{7} = 2200 \text{ foot-pounds.}$$

If we make another revolution in the next second, we place in this wheel $2 \times 2200 = 4400$ foot-pounds. Power accumulated in a fly-wheel overcomes other powers of different grades at different parts of the turn, and an equal power may be used for turning the fly-wheel, if the different powers drawn from it for other places are not greater in sum than the momentum of power placed in the wheel.

Question 304—What do you understand by a machine pump, and what advantage do you gain by it over the pumps before mentioned?

Answer—We understand by a machine pump, a pump which receives its motion from a shaft, under the control of a fly-wheel. With such a pump we have the great advantage of using a regular and equal power to keep it in motion, and neither the starting point of the pump nor the lifting of the valves requires a greater power than required at other points.

Question 305—What do you understand by an engine pump?

Answer—An engine pump is one that is set in motion by an engine, and inasmuch as the engine has, under all circumstances, a shaft, controlled by a fly-wheel, or its substitute, it has the same advantage as a machine pump.

Question 306—What is a steam pump?

Answer—When the rod of a steam piston is used directly as the rod of a plunger or piston in a pump, it is called a steam pump. In these pumps, for the start of a stroke, a greater power is required than for its continuation.

Question 307—What is a duplex pump?

Answer—In a duplex pump we use two cylinders, and the piston in each of them is connected to, and acts with, either a plunger or a piston in the pump. The valve gear of this variety of steam machines is arranged so that the piston-rod of one steam-cylinder controls the valve-gear of the other. Even though the admission of steam to the one steam-cylinder is controlled by the motion of the piston-rod of the other, there is no regularity in the power used, because in the construction there is no accumulator of power.

HEATERS

Question 308—What advantage would you gain, should you feed a boiler with water of 100 degrees, Celsius, instead of zero degrees, or, at the boiling, instead of the freezing point?

Answer—When a boiler is fed with water at the freezing point, for every 61 cubic inches 650 units of heat are required, while for the same weight of water at the boiling point, only 550 units of heat are necessary to evaporate it. By using water at 100 degrees, instead of zero degrees, we would save coal at the rate of one bushel in every six and one-half otherwise consumed.

Question 309—How can water be heated to the boiling point without fuel?

Answer—Water can be heated by exhaust steam that would otherwise be wasted. This must be done in apparatuses called heaters.

Question 310—Are there not in use heaters in which the water is warmed by radiation of heat that would otherwise be lost in a boiler furnace?

Answer—Radiation of heat is used for the purpose of warming water, but the heat that would otherwise be lost is not conveyed to any separate apparatus. Such an arrangement is only a part of the boiler, and is, consequently, falsely styled a heater.

FIG 135a. FIG. 135.

Question 311—What heaters do you know of that are used to heat water with exhaust steam?

Answer—To heat water with exhaust steam two kinds of heaters are in use, a closed and an open heater. The difference between these mechanisms lies in the manner of bringing the heat of the exhaust steam in contact with the water. In the open heater, the steam comes directly in contact with it, that is, the steam is turned upon the water. In the closed heater, the water and steam are separated by sheet metal, and the heat of the steam is indirectly transferred through the metal to the water.

Question 312—How do you explain the construction of a closed heater?

Answer—In Figure 135 a vertical, and in Figure 135a a horizontal section of a closed heater is shown; A, the outside shell, has two compartments, *a*-1 and *a*-2, connected to each other by vertical tubes. The exhaust steam enters at the opening SI, and is forced downward by the partition *n*, which does not extend quite to the bottom, as shown in Figure 135, but leaves an opening. The exhaust steam passes through this and returns on the other side of the partition *n* and escapes at the opening SO into the atmosphere. The cold feed water is pumped through the opening WI into compartment *a*-1 and rises to compartment *a*-2, through the heated vertical tubes, to be discharged into the boiler, through opening WO. The exhaust steam will be more or less condensed by passing through this heater, for this reason this heater is provided with an outlet *d*, through which all condensation can escape to the sewer. The oval, which is indicated by dotted lines, shows the location of a mud-hole for cleaning facilities. The pipes may as well be coil-shaped, as shown in following illustration:

HEATER WITH COIL-SHAPED PIPE.

Question 313—How do you explain the construction of an open heater?

Answer—Figure 136 explains the construction of an open heater. A is a cast-iron casing; the shelves P are arranged in such a way that the exhaust steam, which ente.. at E-1, is forced through a zigzag before it can escape at E-2; the cold water enters at D, and by running from one shelf to the other, passes through the exhaust

steam and settles at the bottom, and may be pumped out into the boiler at opening T, indicated by dotted lines. The water should never rise to the height of the inlet of exhaust E-1; this would obstruct the passage of the latter. To prevent this, a contrivance, called an overflow, is attached to this heater. S is a floater, which rises and floats with the level of the water and at the same time opens an outlet for the superfluous water to escape; it also indicates the height of the water by a ball, which is connected to the floater by means of

FIG. 136.

a rod, extending through the enclosure. A water glass, attached to this heater, would be to more advantage.

Question 314—What is the difference between the action of a closed and an open heater?

Answer—Through the closed heater the water is pumped directly into the boiler, but to the open heater there must be attached an apparatus that supplies the heater with water and from which it must be pumped into the boiler. Consequently, in a closed heater, a lifting and force pump combined can be used, while we use in an open heater a force pump, a pump that stands under water; that is, a pump that is filled with water by the water's weight and not by the atmospheric air pressure; therefore, the pump must stand lower than the heater. In closed heaters, we force the water with all its impurities through the heater into the boiler. In open heaters, into which the water is introduced by an extra apparatus, a tank or pump, the mechanical impurities settle partly on the shelving, and partly on the bottom of the apparatus. Consequently, we pump into the boiler, with the water, only the salts dis-

solved in it, while the mechanical impurities are retained in the open heater, and the air contained in the water, is discharged therefrom by the heat applied, and escapes with the exhaust steam through the exhaust pipe.

Question 315—In which of these heaters can you bring the water to the highest degree of temperature?

Answer—Inasmuch as it is a known fact that water under a high pressure receives a greater temperature than water under a low pressure, and inasmuch as in a closed heater, at the time the pump receives water, it is under one atmosphere's pressure, and as the pump discharges the water under boiler pressure, some men may conclude that in a closed heater the water can be brought to a higher temperature than in an open heater, inasmuch as that in an open heater the water always stands only one atmosphere's air pressure. Others may believe that, as the steam in an open heater comes in direct contact with the water, it can absorb more heat in an open heater than in a closed heater. But these views are equally false. We can bring the water to an equal temperature in both heaters, if the heating surface is equivalent to the amount of water to be heated. Neither in the open nor the closed heater can the temperature of the water be raised higher than 100 degrees, that is, the water cannot be brought to a higher temperature than the boiling point, because the heating material—exhaust steam—carries no more than 100 units of heat as sensible in itself, and only sensible heat can be transferred. Even though the exhaust steam should leave the heater at a temperature of 100 degrees, that would be no proof against this proposition. We must recollect, that the exhaust steam holds its temperature, while the latent heat that is freed by condensation, renews, also, the absorbed sensible heat.

Question 316—What are the advantages and disadvantages of an open heater?

Answer—The advantages are, that we discharge the mechanical impurities and the air from the water before it enters the boiler. Thus we reduce the amount of scale that would otherwise result in the boiler, preventing corrosion of the iron, and, consequently, prolong the life of the boiler. We economize fuel by using the exhaust steam to heat the water, and in the different parts of the boiler, reduce the difference of heat which causes contraction and expansion. The air in the air chamber of the warm water pump is not absorbed by the passing of the warm water, and it does not require much attention to prevent knocking of the water valves. The disadvantages are, that we use two apparatuses for water feed-

ing, one to feed the heater and the other to feed the boiler, and that the latter apparatus, as a warm water pump, requires more attention for its construction than a cold water pump. Besides, we are unable to prevent the oil that is used for lubrication in engines, steam pumps, etc., and is transferred in fine particles by the exhaust steam, from remaining in the water and being carried into the boiler.

Question 317—What are the advantages of a closed heater?

Answer—The advantages are that we use only one water feeding apparatus which is able to lift cold water, force it through the heater and bring it into the boiler as heated water. Besides, oil passing along with the exhaust steam does not enter the boiler, because it does not come in contact with the water. The advantage of saving fuel and preventing extraordinary contraction and expansion of the boiler parts must not be forgotten. The disadvantages are, that we cannot reduce the scale in order to prevent corrosion, and prolong the life of the boiler, and that the air chambers of the pumps require especial observation to prevent knocking of the valves.

Question 318—Is it advisable to use an open tank as a heater for feed water?

Answer—In order to do so, we must insert the exhaust pipe below the water level in the tank, and, therefore, cause a back pressure in engines, pumps and so on, and, consequently, a use of a greater power than would otherwise be necessary. The advantage of such a water heater is an imaginary one.

INSPIRATORS AND INJECTORS

Question 319—To what does an engineer have reference when he speaks of an injector or inspirator; what kind of apparatuses are so styled?

Answer—Injectors and inspirators are apparatuses by means of which the steam generated in a boiler acts directly on water and forces it to enter the boiler from which it was taken.

Question 320—How is it possible that steam of a certain pressure in a boiler can act on water against which the same pressure, from the same boiler is acting, and force the water to enter therein?

Answer—An apparatus, called an injector or inspirator, connects the steam-room of a boiler with its water-room, and it looks unreasonable that where two powers like steam and water stand in the same boiler, under the same pressure one may overbalance the other. In a water glass, which communicates the steam-room with the water-room, we see that the

steam does not influence the water at all, when both are at rest. But it is quite a different thing when one of these matters is set in motion. For illustration we say that we are able to support with our power a ball, of a certain weight, when our power represents the exertion necessary to balance it. But, suppose, for instance, that such a ball is set in motion by the explosion of gun-powder in a cannon, then the utmost resistance we make with our power avails nothing against the power accumulated in the moving ball. When it is possible, therefore, to bring the steam into motion, we cannot doubt that such steam is bound to inject water into the water of the boiler. We can bring steam in motion when the apparatus called an injector or inspirator is capable of cooling off and condensing steam as soon as it is brought in connection with it, and as it is condensed, new steam will immediately rush into the vacated space, and as this process is continued, the steam will be kept in motion. Now, if such an apparatus is so constructed that cool matter, that is, water, is constantly brought in contact with the steam, this water will be injected into the water of the boiler. The apparatus must be so constructed as to bring cold water in contact with the steam, which acts as above stated, to inject it into the water of a boiler.

Question 321—How can cold water be continuously brought in contact with steam in the apparatus, styled an injector or inspirator, if an extra apparatus, for instance, a water tank, is attached?

Answer—A small apparatus, called an atomizer, will illustrate this. Figure 137 shows one. C is a casing which is partly filled up with water. Out of this water extends a vertical pipe R; horizontally to this the pipe B is placed so that if we blow through it, the current of air cannot enter the pipe R, but must pass over R through the opening E left in the casing. The appartus can be filled with water through the opening on top. When the apparatus is partly filled with water, and we blow through the pipe B, the current takes along some air out of the pipe R, causing a suction in it that diminishes the air therein, and the atmospheric air being of greater density than that now in the pipe R, it presses the water upward in the pipe R, and so water is carried along in fine particles by the current in pipe B, and is discharged through the opening E. A trial with

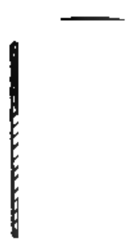


Fig. 137.

an ordinary pipe may quite clearly explain to us the principle involved in raising water in a pipe, when a current of air is blown across its opening. If we place in a pipe, standing at any angle, a piece of loose cotton, and blow at or near its opening in such a direction that the current enters into it, we blow the cotton out of the opposite opening. But if we blow straight across one opening of the pipe, or at such an angle to it that the current cannot enter it, then the cotton placed in the other opening will not be blown out there, but instead, by a kind of suction, it will be drawn out of the opening over which we blew the current. The force of the current blown over such a pipe, when right across it, or at a slight angle to it, takes along a part of the air that is in the pipe; a suction is created in the pipe. When a space is vacated, the air pressure fills it up immediately with other air, which drives the cotton along with its current. In the same way that cotton is lifted or pushed along in this pipe, we can lift water also, if the force of the current corresponds with the weight of the water to be lifted.

Question 322—What is the difference between an injector and an inspirator?

Answer—There is no difference between them. Although the apparatus accomplishes the injection by steam, and both words are used to describe it; yet, generally, the most perfect apparatuses, those that lift the water to a considerable height, are called inspirators, while the more imperfect ones, to which water must be applied by hydrant, or tank pressure, or which can lift water only to a very slight height, such as a couple of feet, are called injectors.

Question 323—How is an injector constructed, and how must it be operated?

Answer—To complete the understanding of the apparatus, in Fig. 138 a construction is given, as it was originally made by the inventor Giffard. In the main body lie two ring-shaped rooms, one above the other, of which the upper one, S, can be brought in communication with the steam pipe E by the cock C, while the lower one W, can be brought in communication with the water reservoir by the channel W and the pipe F. Both ring-shaped chambers are connected by a pipe, which in the steam-chamber S is perforated by a great many holes, while it ends in the water chamber, tapering to a fine opening or mouth, called a steam tuyere, which can be diminished in size by the needle cock N, which is called the stopper. The water chamber opens downwards to a tapering conical mouth *w*, which enters the third ring-shaped chamber, which is the air-chamber A. Its continuation is a narrow,

cylindrical pipe, with a tapering mouth, which enters the air-chamber from below. When the cock C is opened, steam enters through E and rushes from the steam chamber S through the pipe and its mouth into the water chamber, which at the time is filled with air. It takes the air along and therefore sucks water through F. This water mingles immediately with the steam, and with great velocity is brought to the water tuyere in the air chamber A, through the channel of which it could be passed as a free stream of water,

FIG. 138.

like that from the mouth of a syringe, but for an opening similar to that of the water tuyere, but in the opposite direction which receives this stream of water, so that it is driven by gradual increase of its section, into the water feed pipe D, in which it lifts the check valve V and enters through it into the boiler. So the steam which was taken from the boiler is returned to it as condensed water, and the heat that it contained now lies in the feed water. Neither power nor heat is lost through the use of an injector, and the advantage

of feeding the boiler with heated water, must not be overlooked. It must be understood that the amount of steam which is to overcome the water pressure in the boiler, must be proportionately adjusted to the amount of water drawn from the reservoir, otherwise the water will escape through the overflow G and steam will rush through the show-holes *a*. This can be overcome by the screw O and needle-cock N. Should the water overflow through the pipe G, the distance between the steam-jet and the opening indicated by *w*, is too large; this can be lowered by the screw O until the water is in proportion with the steam, which enters through the pipe E. To insure good results, the feed-water should not be too warm, not more than 30 degrees Celsius.

Question 324—Can you describe a more simple construction of an injector than the one just explained?

Answer—Fig. 139 illustrates a construction considerably more simple than Giffard's invention described above. In this construction A is the steam pipe, with a firm steam tuyere. F, the water pipe leading to the reservoir E, the water tuyere

FIG. 139.

arranged in the main casing, adjustable by turning a short shaft, E-1, which acts by-means of a small eccentric therewith connected in a recess of the water tuyere. The shaft E-1 is kept in position by a groove and key, by which, also, it is prevented from falling out of the main casing; S is the overflow, V the check-valve and L the water feed pipe. To this kind of injector the water must be applied by a tank or hydrant, because it has not the power to lift water like the Giffard construction.

Question 325—Can you explain an injector in which the water and steam supply do not have to be separated, adjusted, and in which the adjustment can be made by single motion?

Answer—Such an injector is shown in Fig. 140, in section, and in Fig. 141, in view. It is really an apparatus which in one casing contains two different injectors, placed side by side, and connected together, so that the pressure-room in the first communicates with the condensation room of the second injector. When this apparatus is in operation, the water is drawn in by the first injector and communicated to the second by a certain pressure, and by the second it is driven under a high pressure into the boiler. This apparatus is put in operation as follows: By a slight motion of the hand-lever A, the eccentric pin *b* lifts the beam 00, which allows the steam coming from H to raise the valve *v*, which is small, and therefore not heavily loaded. Then the steam from H passes the tuyere *d*, and is cooled off at once, causing a vacuum, which produces at once an immediate suction of the water, which enters the apparatus at I. This water passes through the

FIG. 140.

FIG 141.

pressure tuyere *f*, the channel and the admitting cock, *e*, at L, where it enters into the atmospheric air to remain until the valve V is fully opened. The opening V turns the cock *e* and closes the channel *m*, and at the same time allows the water to pass back into the channel N, then through the tuyere f-v and the channel M-1, where it passes into the open air again, but as soon as the valve V is fully opened, by the continued motion of the lever, the beam 00 is forced to rise on the opposite side, consequently the large valve V is opened. Then the steam enters under full pressure through the steam tuyere D1, and by acting on the water under pressure in F1, discharges it into the air until by a continued slow motion, the valve V is fully opened and the cock *e* is entirely closed; then the water opens the check valve C, passes through the supply pipe K, and enters the boiler. The whole process is so rapidly effected that the instruction for handling this apparatus may be given in these few words: To put the injector in operation, turn the hand-lever A. By means of this injector water may ordinarily be lifted to a height of from 22 to 24 feet.

ENGINES

Question 326—What do you understand by an engine?

Answer—An engine is a mechanism in which power is generated for the purpose of transferring it to other machinery, thereby putting the same in rotary motion.

Question 327—What different kinds of engines do you know?

Answer—The different powers applied to engines determine their different varieties, and the names by which they are known as steam engines, electrical engines, gas engines, gasoline engines, compressed air engines, water pressure engines, and so on.

Question 328—What main parts are required to construct a steam engine?

Answer—To construct a steam engine we require: 1. A steam cylinder. 2. A crank shaft. 3. A connecting rod. 4. A fly-wheel. 5. A valve gear.

Question 329—What parts belong to a steam cylinder?

Answer—In addition to the cylinder itself, we have the piston acting in it, and connected therewith, the piston-rod, which extends outside of the air-tight cylinder and by following the piston back and forth, sets the machinery in motion. To close the cylinder two cylinder heads are required, one of which must be provided with a stuffing box, through which,

by means of a packing, the piston rod runs air-tight. In adtion to these , the guide-rods and cross-head are required to confine the motion of the piston-rod to the axis of the cylinder. The cylinder must also be provided with channels to admit, and discharge the steam to, and from it.

Question 330—What are the names of the single parts of a cylinder?

Answer—Fig. 142 shows a longitudinal section of a cylinder in which are represented all parts of the apparatus. In stationary engineering that part of the cylinder out of which

FIG. 142.

the piston-rod extends, is styled the front, and the opposite part, the back of it; and it being necessary to describe a good many parts that are attached, both to the front and the back, we will indicate parts bearing the same name, by the same letter, but those lying at the front of the cylinder will be indicated by capital letters, and those at the back with small letters. The cylinder is indicated in the figure A, the cylinder heads by Bb. In each cylinder the recesses are indicated by C. c. The bore of the cylinder, in which the piston moves, is indicated by D, and the diameter of the cylinder is larger at both ends. These we call the counter-bores, and they are indicated by Ee. The flanges of the cylinder are indicated by Ff, the drain cock by Gg, the steam channels by Hh, the steam ports by Ii, the exhaust port by K, the exhaust pipe by L, the chest face by M, the gland of the stuffing box by N, its packing by C, the piston-rod by P, the spider by Q, the packing-rings by R, the follower by S. The three pieces, Q, R and S together, constitute the piston. TT are the guide-rods, U is the cross-head, V is the cross-head wrist-pin, and WW are the bearings of the cross-head.

Question 331—Why is a counter-bore necessary in addition to a bore in a steam cylinder?

Answer—The bore in a cylinder is gradually made larger and larger by the strokes of the piston, and so, after a certain period of time a shoulder exists on both sides of the stroke against which the piston is bound to knock, as its motion is transferred through the piston-rod by means of a connecting rod, and while this gradual wear is forming the shoulder, the position of the piston in the cylinder is not always the same after every stroke, therefore, when every stroke reaches into a counterbore, the formation of a shoulder is prevented.

Question 332—Why is a recess formed in each cylinder head?

Answer—The position of the piston in the cylinder varies according to its stroke, and so its position with reference to the cylinder head changes accordingly, and the distance between the piston and cylinder-head is greater, and less by turns, therefore, the admission to, and the discharge of, the steam from the cylinder, would, under the circumstances, be cramped, without the recess alluded to. Therefore, for the purpose of having a free admission and discharge of steam, a recess in the cylinder head is made, and the position of the steam channels is such that the recess forms a continuation of them, thus affording a sufficient amount of steam between the cylinder head and piston, when the latter is at the end of its stroke.

Question 333—How is a steam piston best constructed?

Answer—The piston must have an elastic packing. The wear and tear lies in the bore and in the packing, and the elasticity of the packing must be such as to always fill up the space which would otherwise exist between the bore and packing, or the piston would not fit tightly in the bore during continued use. In old times the packing was made from hemp, prepared with mutton tallow. This packing does not last long and it is troublesome and a waste of time to make it, to pack and renew it. Therefore, another kind of elastic packing must be used. In our days, elastic metal rings are used for such a packing. To get the elasticity in it the ring is turned a little larger in diameter than the bore. The ring must be split, and the ends of the split compressed so that the ring can be inserted into the bore. In its tendency to take its original size, it presses against the bore. This ring must be split

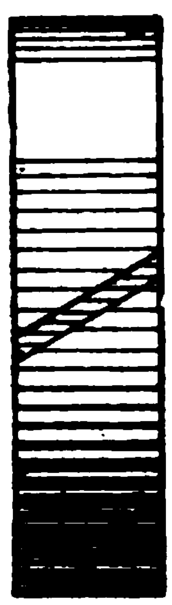


FIG. 143.

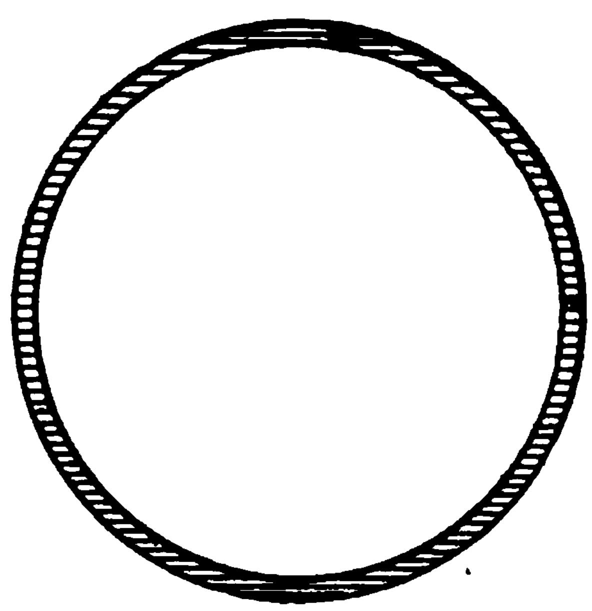


FIG. 144.

obliquely. Figure 143 shows a top view of such a split ring, and Figure 144 a side view of it. We need an oblique split, otherwise a shoulder would be formed in the cylinder. Two of these rings are required and must be placed in such a way that neither split lies on top of the other; in each of these rings we use another split ring which is also turned so that its outside diameter is a little larger than the inner diameter of the ring first mentioned. The split should be at right angles with the face. We fasten a spider to the piston-rod, run the free end of it through the cylinder, and through the stuffing box of the front cylinder head, and push the spider through the counter-bore and into the bore of the cylinder far enough to receive one of the packing rings to be inserted. To do this best, press the outer packing ring together and hold it so by means of a wire bound around it and push it into the bore, thereby pushing the spider ahead. Let the wire

slip off the ring, then push the inner ring into this one, and push the pair of the rings so formed further, so that the second pair of rings can be inserted into the bore in the same way as the first. After the two pair of rings are so located in the bore, the follower may be placed therein and screwed against the spider. The piston must be so constructed that each pair of its rings will have the same face, and they must be so smoothly ground as to fit the spider, the follower, and each other perfectly, and the hub of the spider extending around the piston-rod must be of sufficient width that when the follower is tightened up, the packings, follower and spider will be held together air-tight, without preventing the expansion of the rings against the bore; that is, while the packing rings must not move lengthwise of the bore between the spider and the follower, they should not be prevented from expanding crosswise.

Question 334—For what purpose are bearings used on a cross-head?

Answer—By the motion of the piston-rod, the cross-head wrist-pin suffers, not alone from wear in the axis of the cylinder, but it is also influenced obliquely by the connecting rod, and the same action results upon the guide rods; so to correct and prevent the wearing between cross-head and guides bearings, adjusted by set screws, are necessary to keep the piston-rod acting in the center line of the steam cylinder.

Question 335—How is a packing prepared for the stuffing box of piston-rod?

Answer—When we are unable to get the prepared packing, we use hemp fibers by arranging them in parallel layers and making small strips thereof by greasing them with a mixture of three-quarters mutton tallow and one-quarter bees wax. Braid these strings together and insert the braid so prepared into the stuffing box and press it down by means of the gland until it becomes air-tight packing.

Question 336—What is meant by a shaft?

Answer—A stiff rod of any shape becomes a shaft as soon as it revolves around its axis; but in order to be a shaft it must revolve, either between center pins, or in journal boxes.

Question 337—What is understood by a crank shaft?

Answer—A crank shaft is one to which a wrist-pin, smaller in size, is fastened outside of the center of the shaft.

Question 338—How do you fasten a wrist-pin to a shaft, and what do you call the crank so formed?

Answer—The wrist-pin fastened directly to the shaft, as illustrated in Figure 145, is called a common crank; or in Figure 146, where it is fastened to the shaft by a contrivance, called a web, in which case it is called a web crank. In Figure 147,

FIG. 145.

the wrist-pin is fastened to the shaft by means of a round plate concentric to the shaft, making what is called a disc-crank. In Figure 148, a fly-wheel crank is illustrated, constituted by fastening a wrist-pin to a fly-wheel. Figure 149 shows two pieces of shafting made by two webs and a wrist-pin, which constitute what is called a double crank.

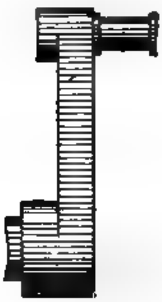


FIG. 146.

FIG. 147.

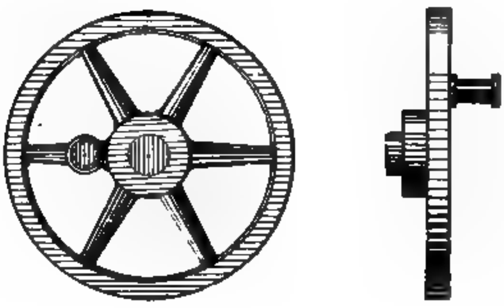


FIG. 148.

Question 339—How must a connecting rod be constructed?

Answer—A connecting rod cannot be made of a single piece of metal, on account of the bores for the wrist-pins, which, under constant wear and tear, have a tendency to become oval and cause knocking in the engine. Consequently, three pieces are required, a middle piece, at each end of which a box is placed for the reception of the wrist-pins. These boxes are split,

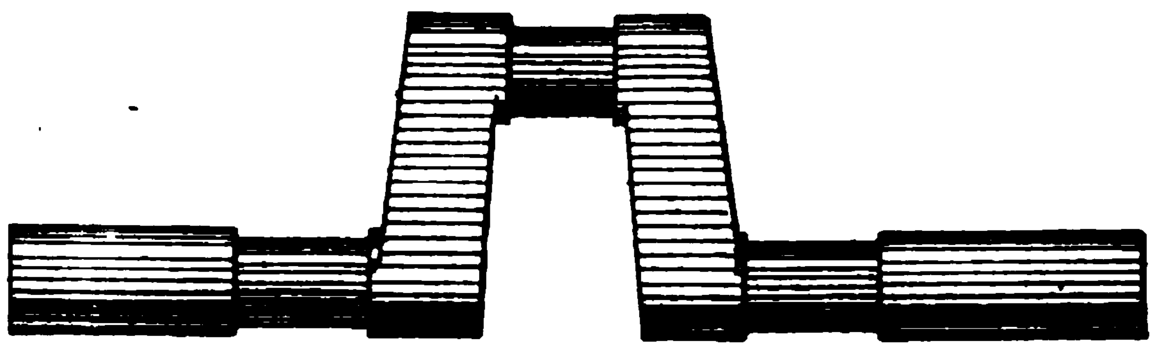


FIG. 149.

held together against the ends of the middle piece by means of straps, each fastened with a gib and key and set screws. Figure 150 shows a side view of a connecting rod, Figure 151, a top view of the middle piece, Figure 152 an end view of the middle piece and Figure 153 shows a section of one end

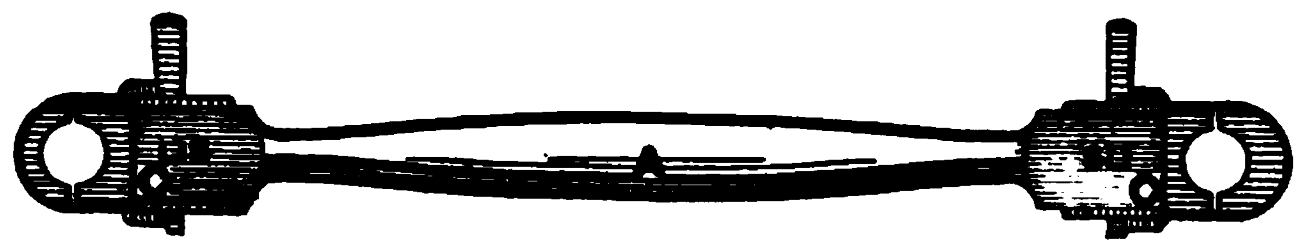


FIG. 150.

of the connecting-rod. Figure 154 shows the gib and key lying in their position against each other and attached to the middle piece. A is the middle piece. It is perforated at both ends so that the gib and key may pass through; *b* shows the perforations. This middle piece is made of a bar, in an

FIG 151. FIG. 152.

oblong section. The ends, C, which are called the stub ends, must be at right angles to the sides of the bar. D-1 and D-2 are the split boxes, called the brasses. The base of D-1 rests against the stub end, while the part D-2 is rounded off, and the strap E is bound to hold the two pieces of the split boxes together with the middle piece. The strap is perforated at *e*, with oblong holes, the same size as in the middle piece A, but

with it they do not correspond. They are arranged as Figure 154 shows. Into these perforations of the strap and middle piece, a gib, *c*, is first placed, so that its noses rest on the strap so that the gib cannot slip out of the hole; the key H is inserted therein also, and when it is driven in, the split box,

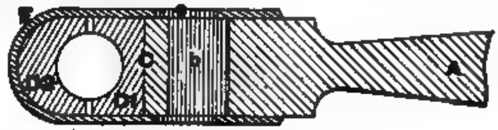


FIG. 153.

FIG. 154.

with its parts placed tightly against the wrist-pin and held in this position by a set-screw S and the stub end of the connecting rod. On the sides of the split boxes are shoulders to prevent the strap from moving sideways.

Question 340—How can we attach the connecting rod to a wrist-pin, so that its action will be neither too loose nor too tight?

Answer—After the gib and key are inserted, the key must be driven tightly, so that no motion of the connecting rod can be made. Then blacken a finger with the grease that has been used as lubrication till highly discolored and make a mark on the upper part of the key, where it enters the strap; the key should then be driven loose, gradually, until the motion of the connecting rod is allowed again; all that has to be recollected when tightening the brasses hereafter is the distance the mark on the key moved before the connecting rod was movable again. The pieces that constitute the split boxes are called the brasses of the connecting-rod.

Question 341—What must be done with the brasses when they lie too close together and the wrist-pin does not fit tightly therein?

Answer—We must file off the ends of the brasses that meet each other, so that the space is left for tightening them up again.

Question 342—By each correction of the brasses, the connecting-rod must become shorter and shorter; does this necessitate new brasses when the connecting-rod becomes too short?

Answer—No; we can put in lining pieces of sheet brass or iron between the stub end and the brass that must meet it.

Question 343—For what purpose is a fly-wheel used on an engine?

Answer—The object of a fly-wheel on an engine is two-fold. When the steam-piston is at the end of its stroke, the piston-rod, connecting-rod and crank lie in a straight line. We call this the dead line of an engine, because all the power that may act against the piston cannot move it and set the shaft in rotation. Were the power great enough when this condition exists, it could do no more than break the journal boxes in which lies the shaft or push them off their seats. We use the fly-wheel to break the dead line and enable the engine to get in motion. In addition to this purpose, the fly-wheel must not only equalize the different actions of the power during the stroke, but also equalize the different counteractions of machinery against the engine during a stroke of the piston.

Question 344—What do you call the journal-boxes in which lies the crank-shaft of an engine?

Answer—The journal that lies between the crank and valve-gear is called the main pillow-block box, and the other one is called the outer, or the tail pillow-block box.

Question 345—What constitutes the valve-gear on a steam engine?

Answer—A valve on the chest face of a steam cylinder is a contrivance which automatically admits steam to the latter.

Question 346—What contrivance do you use to set such an appliance in motion?

Answer—We use either a crank, an eccentric, a cam, or the steam cylinder itself.

Question 347—What is an eccentric and how does it vary from a crank?

Answer—An eccentric may be considered as a wrist-pin fastened to a shaft, with its center out of line with the center of shaft. But it differs from a crank inasmuch as the wrist-pin which forms the eccentric is of larger diameter than the shaft that it surrounds. The crank wrist-pin is surrounded by brasses and the eccentric by eccentric straps.

Question 348—What is a cam?

Answer—A cam is a projection on a shaft around which it revolves, and causes, by its projection and its recess, alternate motion to another contrivance coming in contact with it.

Question 349—How must a valve act in an engine?

Answer—Each steam cylinder requires channels to admit the steam necessary to move the piston and keep it in motion, and likewise the channels are necessary to discharge steam from the cylinder at the same time on the other side of the piston for the purpose of diminishing, as much as possible, the counteraction. In the steam cylinder this takes place alternately; on one side of the piston steam is admitted, while on the other it is discharged during the same stroke. During the next stroke the same effects are produced only at opposite ends of the cylinder. Like the piston, the valve must consequently make alternate motions.

Question 350—How do you construct a web-crank?

Answer—The web of a crank is shrunk on the shaft as well as on the wrist-pin, and the hole that is bored for the purpose, must be surrounded by iron or steel of a thickness of at least one-fourth part of the diameter of the holes. The circles so constructed will then form a web as soon as tangents are drawn mutual to both circles as Figure 155 shows, in which A is the shaft, B the wrist-pin, the surroundings of which are indicated by *a* and *b*, and the tangential lines *t*1 and *t*2 form the web C.

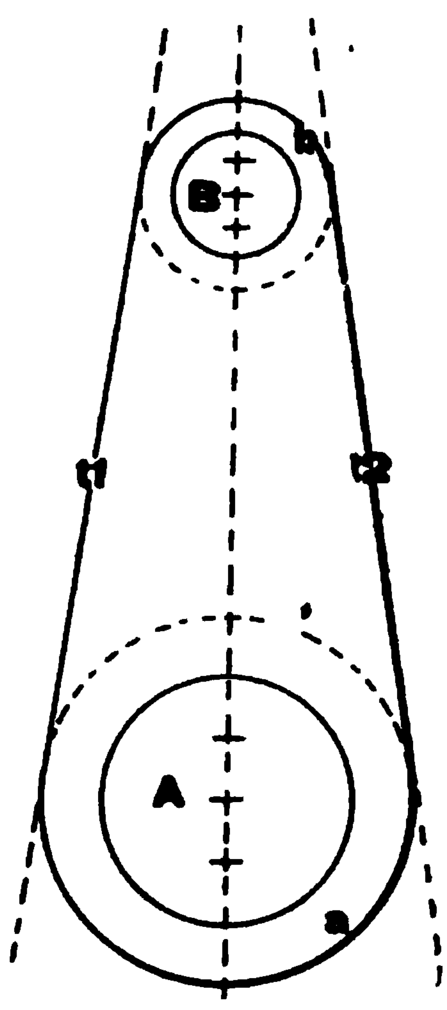


FIG. 155.

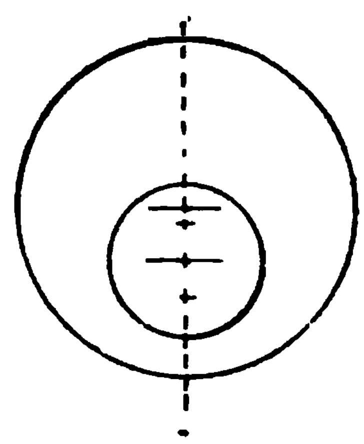


FIG. 156.

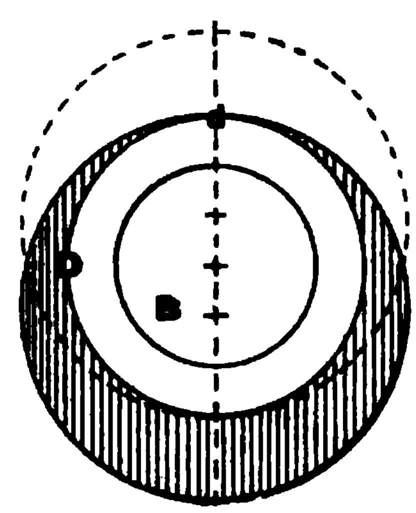


FIG. 157.

Question 351—How long is the stroke of a crank?

Answer—The stroke of a crank is equal to twice the distance between its two centers.

Question 352—How must an eccentric be constructed, and what is the nature of its action?

Answer—An eccentric is a round plate, around which, for engine purposes, eccentric straps are placed. This plate surrounds the shaft, which is inserted through a hole made therein not nearer to the circumference of the plate than one-fourth of the diameter of the shaft. Eccentrics are either keyed to the shaft or are fastened thereto by means of set screws. The diameter that is drawn through the center of the shaft and center of the eccentric, is divided by the bore in two sections, one small and one large one. The small one is called the small radius of the eccentric, and the largest the great radius of the eccentric. (See Figure 156.) The result produced by the motion of the eccentric is called the throw of the eccentric. The throw of an eccentric is equal to the great radius minus the small radius thereof—or the large part thereof—minus the small part—or, in other words, equal to twice the distance between its two centers. It is also equal to the diameter of the eccentric minus 1½ times the diameter of the shaft. If a circle D is drawn concentric to the shaft through the weak point of the eccentric *d* (refer to Figure 157), the circular line D must be called a dead line, because it could not move an object touching it. The hatched part of the eccentric produces the throw, and the dotted line at Figure 157 indicates the position of the eccentric after the throw is made.

Question 353—What is understood by "A Steam Chest?"

Answer—A steam chest is a casing which is placed on the steam cylinder, in which the steam valve operates. The motion of the steam valve results from connections outside the chest; therefore, a valve-rod extends through the steam chest and is kept there steam-tight by means of a stuffing box, packing and gland. In Figure 158, which shows a part of a steam cylinder, the chest face is indicated by M. The steam ports

FIG. 158.

are indicated by Ii, the exhaust port is indicated by K, the exhaust pipe by L, and the portion of the steam cylinder shown is indicated by A. Hh represent the two steam channels. B is the steam valve. The recess in this, C, is called the exhaust cavity of the steam valve. D is the chest itself, with the valve-rod stuffing box E, the gland F and the packing G. The valve-rod N, which extends through the stuffing box and has on the outside a link O, is connected to the steam valve, either by gem nuts or by a yoke. The chest which is fastened tightly onto the steam cylinder, is covered by a steam-tight chest cover, called also a bonnet, which is indicated by P. The steam supply-pipe Q, leads to the chest. The link O, of the valve-rod, serves for connection, either with a crank, by means of a connecting-rod, or with an eccentric, by means of an eccentric-rod, or with a cam, by means of a cam-rod.

Question 354—What is the motion of a steam valve in a full pressure engine?

Answer—We understand by a full pressure engine, an engine in which the steam acts with the same pressure from the beginning to the end of the stroke. When the engine is in dead line, that means the steam-piston is at the end of its stroke, no power is able to bring the piston in motion, unless the fly-wheel assists in breaking the dead line. At the moment the piston is at the end of its stroke, no steam need be applied, but as soon as the fly-wheel starts the stroke, the steam-valve is therefore brought in motion to admit steam. At the same time that the steam is admitted at one side, it must be discharged at the other side of the piston, whence it exhausts and is brought in contact with the atmospheric air. Therefore, the steam valve must just cover both steam ports, while the engine is in dead line, but it is set in motion as soon as the piston moves. In perfect operation it must admit steam at one side of the piston and discharge it out of the other side. But as the piston approaches the end of the stroke again, the two ports must be closed; therefore, the valve, which starts its motion in the same direction as the piston, must reverse its motion before the piston finishes its stroke in order to close the ports again when the piston reaches the end of its stroke. The continuity of these motions produce the orderly operation of the engine. The steam valve on a full pressure engine must, therefore, make during every stroke of the piston a forward and backward motion, and must close both the ports while engine is in dead line. During the whole of one stroke one steam port is open, during the whole of the next stroke, the opposite port must be open.

Question 355—How must the ports be arranged at the chest face for a full pressure engine?

Answer—The exhaust port should be at the middle of the cylinder, and must be twice the width of a steam port. The walls that lie between the steam port and the exhaust port are called the steam bridges; each of them must be equal in width to a steam port. At the outer sides of the steam ports, a projection rises slightly above the surface of the cylinder and in line with the chest face, the width of this projection being somewhat less than that of a steam port. The opening of the steam port should be oblong in shape, and its length should be at least five times greater than its width. The area of a port must be equal to the area of the steam supply pipe, the diameter of which should be equal to at least one-fifth of the diameter of the steam cylinder.

Question 356—What should be the dimensions of a steam valve in a full pressure engine?

Answer—In such an engine the length of a steam valve must be equal to the width of the steam port. The exhaust cavity must be equal to four times the width of the steam port. We call that part of a valve that lies against the chest-face the valve-face; consequently, on each side of the exhaust cavity the valve-face shows once the width of the steam port, plus twice the width of a steam port.

Question 357—How, and to what extent does the steam valve in a full pressure engine travel during one revolution?

Answer—The steam valve has one port open, when the piston is in about the middle of the stroke. It closes this port when

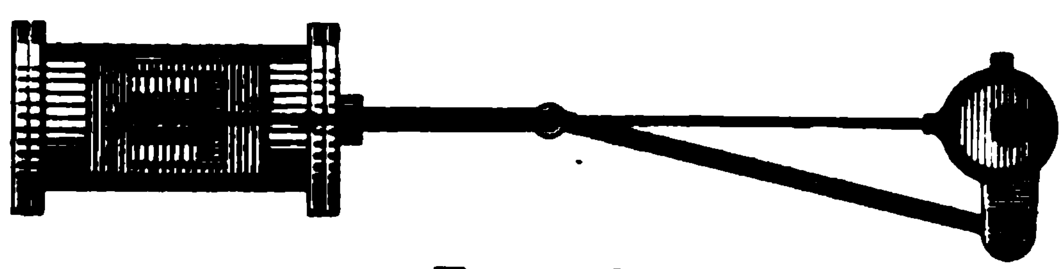


FIG. 159.

the stroke is finished. By the next stroke the opposite steam port will be opened and closed; consequently, the whole course of a steam valve is equal to twice the width of a steam port. (See Figures 159, 160 and 161, which show the valve

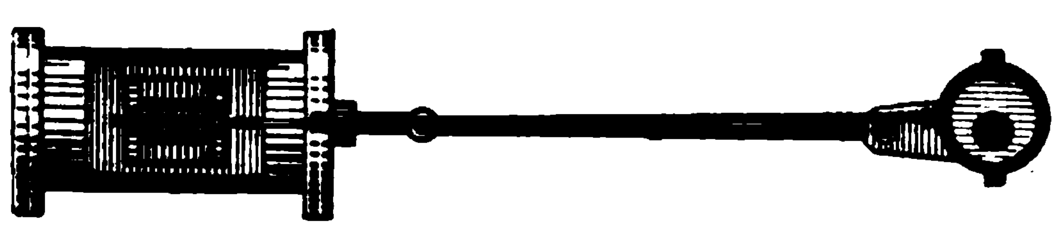


FIG. 160.

in its different positions during the revolution). Figure 159 shows a front port open. Figure 160 shows the crank at the end of the stroke. Figure 161 shows the back port open;

FIG. 161.

then the valve falls back, as shown in Figure 160, when the engine is in dead line.

Question 358—What should be the length of a crank designed to regulate the traveling way of a valve?

Answer—In length the crank must be equal to once the width of a steam port because its stroke must be twice that length, that is twice the width of a steam port. The crank working the valve of a full pressure engine must, in other words, have the width of a steam port between its two centers.

Question 359—In what position must the valve-crank stand, with reference to the engine-crank, in a full pressure engine?

Answer—The line extending through the two centers of a crank is called the middle line of the crank. Now, for a full pressure engine the middle line of the valve-crank should be at

FIG. 162.

FIG. 163.

right angles to the middle line of the engine-crank, because when the engine-crank lies in a dead line, then the valve is bound to lie in the middle of its seat, and the same must take place when the stroke is reversed; the middle line of the valve-crank is bound to be at right angles to the middle line of the engine-crank, as can be seen in Figures 162 and 163. Should the valve-crank not be at right angles to the engine-crank, as explained in Figures 164 and 165, the valve would not lie in the middle of its seat while the engine-crank lies in dead line, nor would the valve be in the middle of its seat upon the reversal of the stroke.

FIG. 164.

FIG. 165.

Question 360—What throw must an eccentric have in order to regulate the motion of the valve in a full pressure engine?

Answer—We know that the stroke must be equal to the throw, if the distance between the two centers of the crank and the eccentric is equal. Consequently, the throw of an eccentric must be equal to twice the width of a steam port.

Question 361—In what position must the great radius of an eccentric stand with reference to the engine-crank, when it regulates the motion of a valve in a full pressure engine?

Answer—The great radius of an eccentric must, for this purpose, be at right angles to the engine crank. The center of an eccentric acts like the center of a wrist-pin; therefore, the

action of a valve-crank and an eccentric is the same if the distance between the two centers of both is the same, and while the great radius of the eccentric can be considered at its middle line, they both require the same position with reference to the engine crank in a full pressure engine.

Question 362—What is the difference between a right-hand and a left-hand motion?

Answer—We call a circular motion, if it takes place like the handle of a coffee mill, or like the handle of a clock-dial, a right-hand motion, and the opposite, a left-hand motion.

Question 363—How do we decide which motion an engine makes?

Answer—To decide which motion an engine makes, we must stand in front of it.

Question 364—Where must we place ourselves in order to say correctly that we are standing in front of an engine?

Answer—We are standing in front of an engine when the engine crank lies between us and the valve-gear. We know that the valve-crank, the eccentric and the cam, are parts of a valve-gear; when, therefore, the engine-crank covers from view a part of the valve-crank or eccentric or cam, as Figures 166,

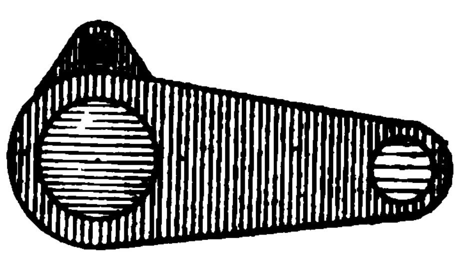


FIG. 166.

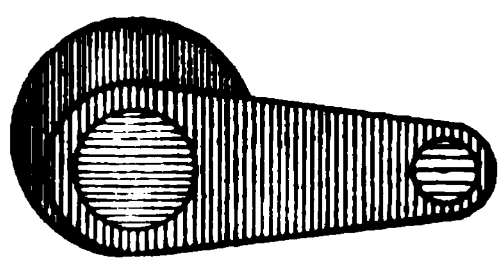


FIG. 167.

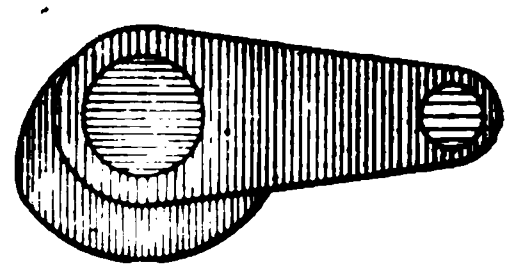


FIG. 168.

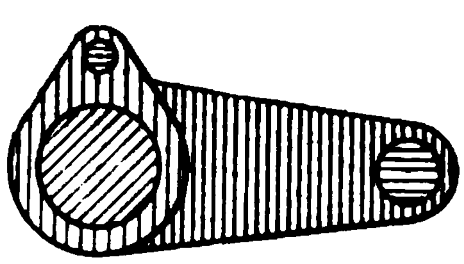


FIG. 169.

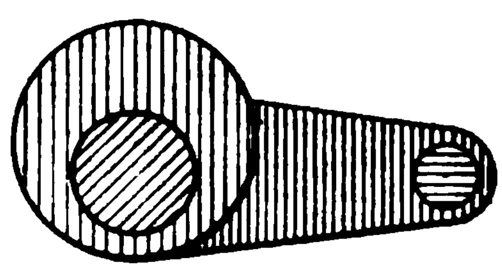


FIG. 170.

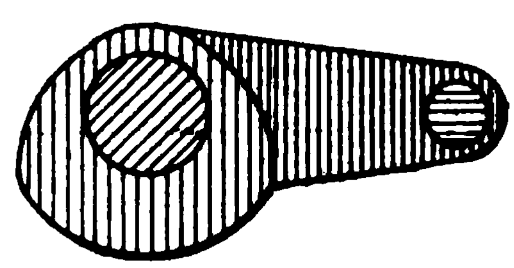


FIG. 171.

167 and 168 show, we are in front of the engine. But if the valve-crank or eccentric or cam, covers from view a part of the engine-crank, as Figures 169, 170 and 171 show, then we are in the rear of the engine.

Question 365—At what time is an engine right-handed, and at what time is it left-handed?

Answer—When we are in front of an engine and see the valve-crank, or the great radius of the eccentric, or the big part of the cam lying to the right of the engine-crank, the engine is a right-handed one. If the valve-crank or the radius of the

eccentric, or the big part of the cam lies to the left of the engine-crank, while we are in front of the engine, it is left-handed.

Question 366—In how many different positions can a steam cylinder be arranged with reference to the horizon and to the crank-shaft, and what is the engine called accordingly?

Answer—With reference to the horizon, the steam cylinder of an engine may lie parallel thereto, in which case we have what is called a horizontal engine; or the steam cylinder may be vertically in plumb, then we have a vertical engine, and if the steam cylinder lies in an incline position with reference to the horizon, we call it an incline engine. If the steam cylinder stands vertically, or in incline, the crank-shaft may be either above or below it. If the cylinder is above the crank-shaft we have an inverted engine, and if the cylinder is below the crank-shaft, this makes an upright engine. When an engine lies in a horizontal position, the cylinder may lie either towards the right or the left of the crank-shaft; we speak, then, of an over-running or under-running engine, but no matter whether it lies to the right or to the left, it can be either an

FIG. 172.

FIG. 173.

over-running or under-running engine, which depends upon peculiar circumstances.

Question 367—How do we determine whether an engine is over-running or under-running?

Answer—If the engine-crank lies towards the cylinder, and the valve-crank, or the big part of the eccentric or the big part of the cam lies above the crank-shaft, the engine is over-running. If the valve-crank or the big part of the eccentric, or the big part of the cam, stands below the crank-shaft while the engine-crank lies toward the cylinder, the engine is under-running. It is quite immaterial whether we decide this by standing in front or in the rear of an engine.

Question 368—What do you call each of the engines that are illustrated in Figures 172 to 179, inclusive?

Answer—Figure 172 is a right-handed, inverted, vertical full-pressure engine. Figure 173 is called a right-handed, upright vertical full-pressure engine. Figure 174 is a right-handed, inverted, inclined full-pressure engine. Figure 175 is a

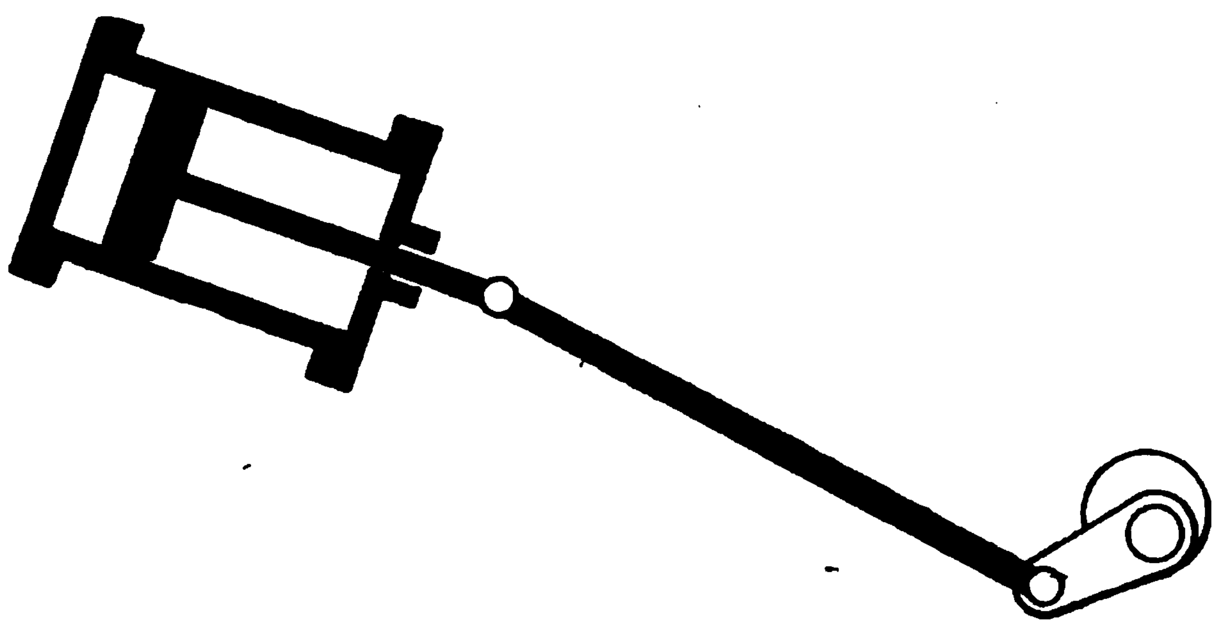


FIG. 174.

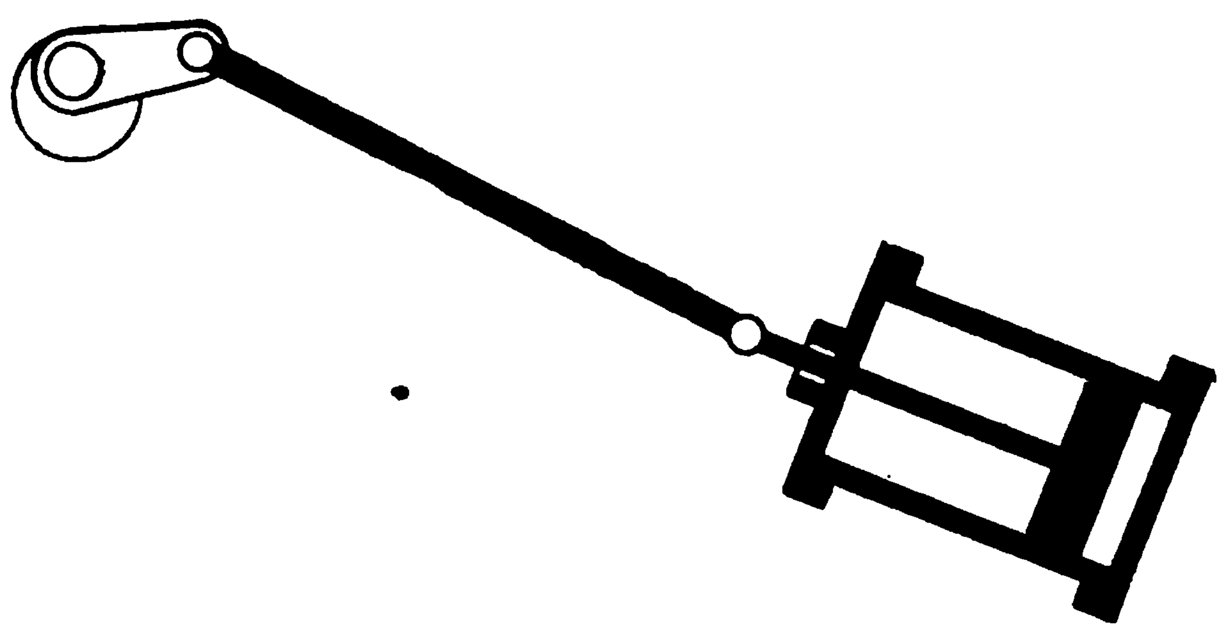


FIG. 175.

right-handed, upright, inclined, full-pressure engine. Figure 176 represents a right-handed, over-running, full-pressure engine. Figure 177 represents a left-handed, under-running, full-pressure engine. Figure 178 is a left-handed over-running full pressure engine. Figure 179 is called a right-handed, under-running full-pressure engine.

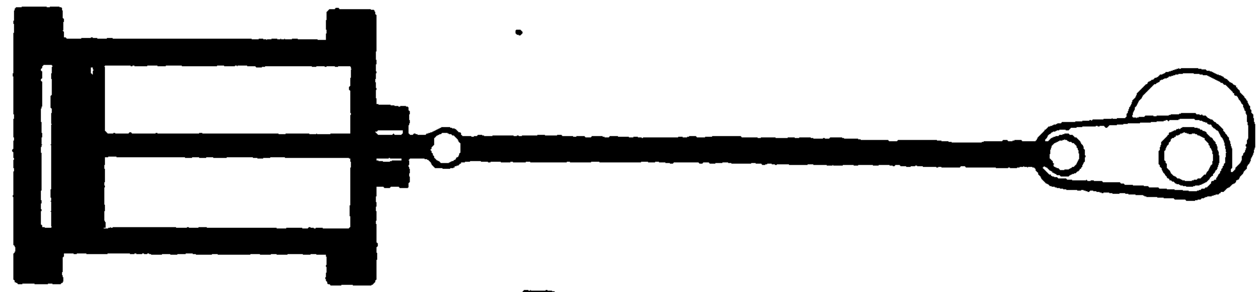


FIG. 176.

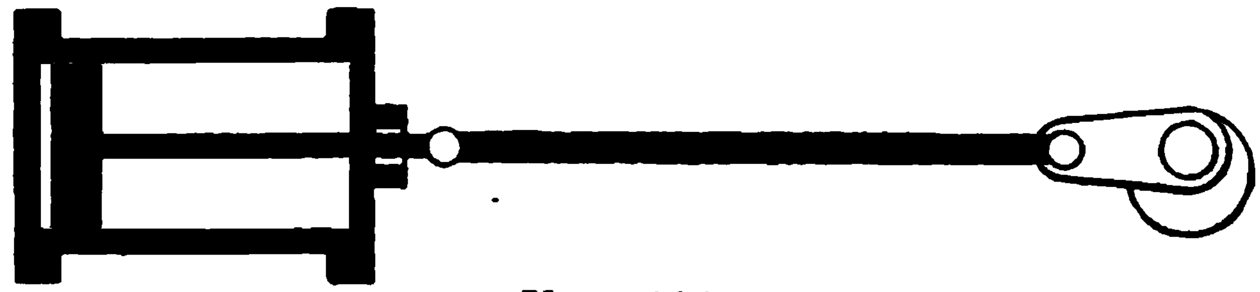


FIG. 177.

FIG. 178.

FIG. 179.

Question 369—What is understood by a direct-acting valve-gear, and what by an indirect-acting valve-gear?

Answer—If an eccentric, valve-crank, or cam, acts in the same plane in which a valve moves, we are able to connect the valve-rod direct, by means of an eccentric rod.connecting-rod, or cam-rod,with the respective mechanism that should set the valve in motion; therefore this kind of valve-gear is called a direct-acting valve-gear. But, if the contrivance intended to set the valve in motion, does not act in the same plane in which the valve moves, then we require an intermitting piece, a rocker, between the valve and the contrivances intended to set it.in motion; therefore, the valve-gear is styled an indirect valve-gear.

Question 370—What is a rocker?

Answer—A rocker is formed by a shaft on which lever-arms act from two opposite directions. The rocker forms a lever in which the shaft represents the fulcrum. In Figures 180 and 181 a rocker is represented in two views. A is the shaft and B and C are the arms. When the rocker is used in combination with the valve-gear, one rocker-arm is connected with the valve-rod and the other with the rod that belongs to the

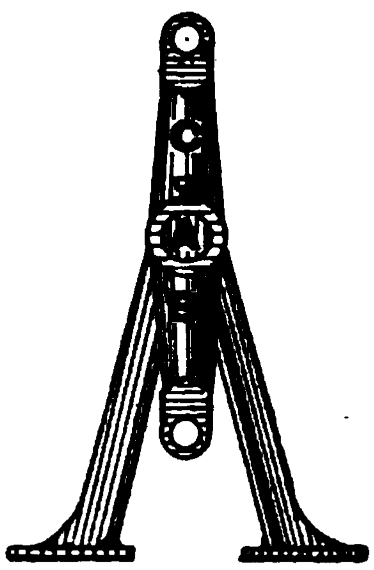


FIG. 180.

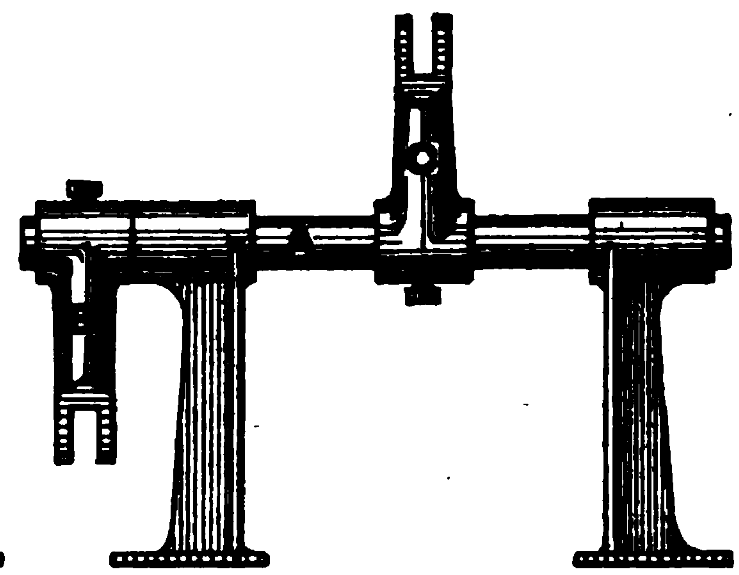


FIG. 181.

contrivance that sets the valve in motion. In Figure 182 we see a horizontal engine, constructed with such a rocker motion, while Figure 183 shows such an engine with direct valve-gear; while the first is a sectional view, with its valve on top, in the second the valve appears on the side of the cylinder, in line with the center of the shaft.

Question 371—Is there a difference in the action of a direct and an indirect-acting valve-gear?

Answer—The rocker changes the direction of an engine. If the engine without a rocker is right-handed, with it, it will be left-handed.

Question 372—Does a rocker change, in the same way, an over-running engine into an under-running one?

Answer—Figure 184 shows a left-handed, over-running, full-pressure engine. Figure 185 shows the same engine with a rocker, as a right-handed, over-running, full-pressure engine.

Question 373—How must the rocker be set on a full pressure engine?

Answer—If the engine is in dead line, and, consequently, the great radius of the eccentric or the middle line of the valve-crank stands at right angles to the engine-crank, then the rocker must stand at right angles to the dead line, consequently, parallel to the great radius of eccentric or middle line of the valve-crank.

Question 374—How must the valve-gear be set for a full pressure engine with direct valve-gear, if an eccentric is used?

Answer—The great radius of an eccentric must be placed at right angles to the engine-crank in the direction the engine is to run, then the engine will be placed in a dead line and the valve mounted on the chest-face so that it covers the ports equally, then the valve-rod, with its yoke, must be slipped over the valve and the valve-rod linked to the eccentric-rod, and this rod adjusted to the eccentric-straps by steady nuts.

FIG. 182.

FIG. 183.

Question 375—How do you set an indirect valve-gear to an engine on which an eccentric is operating?

Answer—Place the great radius at right angles to the engine-crank, set the engine in dead fine, the rocker in plumb to dead line and connect the eccentric with the lower rocker-arm, then mount the valve, covering equally the steam ports and chest-face, insert valve-rod and connect it with the top rocker-arm, and then adjust the valve-rod by the gem-nuts.

FIG. 184.

FIG. 185.

Question 376—How must a cam be constructed which is intended to act on a full pressure engine?

Answer—Three circles, concentric to the shaft, must control the valve by means of the cam-rod. These three circles must stand at a distance from each other equal to once the width of a steam port. The inner circle must stand at a distance from the shaft equal to one-fourth of the diameter of the bore. A diameter intersects the three circles, and at the intersecting points of the middle circle a curve is drawn, beveling off the outer and inner circle, as the diagram in Figure 186 illustrates. O is the outer circle, M the middle, and I the inner circle; S is the shaft and D the diameter. When the cam-rod is held against the middle circle, the valve closes both steam ports; when acting against the inner circle, the back steam port is open and when acting against the outer circle, the front steam port is open. The heavy line in the figure represents the circumference of the cam, against which the cam-rod is acting. The diameter D intersects the inner

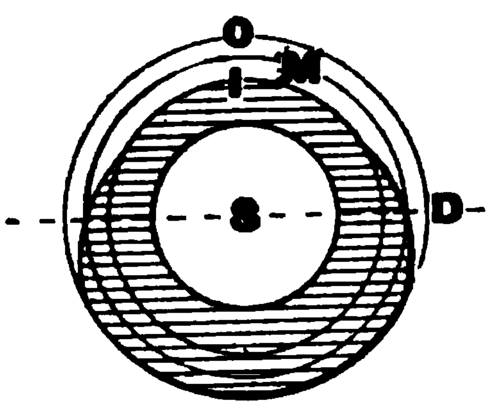


FIG. 186.

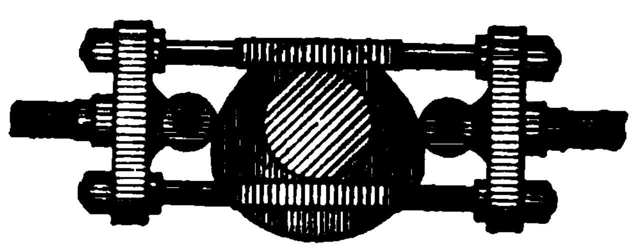


FIG. 187.

circle M in the points, *ii*, and divides the cam into a large and small part, and must lie in the same plan as the middle line of the engine crank. Every line that is drawn through the center of the bore of the cam must be between the circumference of it, equal to 1½ times the diameter of the shaft plus twice the width of a steam port; so the curve that bevels off from the middle circle toward the inner and outer one, is distinct.

Question 377—How is the cam-rod joined to the cam so that the latter can act upon it?

Answer—The cam-rod has at its end a yoke that may be slipped over the crank shaft, to which rollers are attached, which act against the circumference of the cam, so the valve and the cam rod are kept straight. Figure 187 illustrates the action of the cam against the cam-rod fully.

Question 378—How can you prove that the big part of the cam must be toward the right of the engine-crank when the engine is a right handed one?

Answer—In Figure 188 an engine with a cam valve-gear, for full pressure, acting right-handed, is shown. The arrows indicate the direction in which the valve will start, and also in what direction the rotation of the shaft takes place.

FIG. 188.

Question 379—What do you call an engine, in which the steam cylinder is filled only during part of the stroke with steam as it comes from the boiler, and in which the steam must expand to create power during the latter part of the stroke?

Answer—Such an engine is called an early cut-off engine. The only part of the steam cylinder that is filled with steam of full pressure is the three-fourths, one-half, three-eighths, one-fourth, one-fifth, and so on, means the part of the cylinder to be so filled, and therefore gives the name of the early cut-off, and consequently, the engine is called three-fourths, one-half, three-eighths, one-fourth, one-fifth, and so on, early cut-off engine. An engine that acts under full pressure during the whole stroke is called a common cut-off engine.

Question 380—How does the valve-gear of an early cut-off engine differ from that of a full pressure engine?

Answer—In a full pressure engine the valve is just long enough to cover the steam ports. The valve for an early cut-off engine must be made longer because the valve travels during the entire stroke and must open the steam port, close it at the point of cut-off, and keep it closed until the completion of the stroke. This necessitates increased valve-travel, hence

the eccentric must have greater throw than that on a full pressure engine.

Question 381—How do you explain the construction of a valve, such as is necessary for an early cut-off engine, when it stands under control of an eccentric or a valve-crank?

Answer—The valve that must be used for this purpose must be larger than the valve used for a full-pressure engine, and is called a D lap-valve, on account of its peculiar shape. We also use for an early cut-off engine, as described, a D-valve, but it must be of larger size; it must reach and lap over one port while the engine is in dead line, and therefore, we call it a D lap-valve. This valve must be constructed so that it covers, not only the steam ports, and that it is not only equal to six times the width of the steam port, but the lap must also be added to this, as it is required to effect the early cut-off. While it is not necessary to change the ports in the steam cylinder, the exhaust cavity in the D lap-valve can by no means be made larger than four times the width of a steam port, and it is bound to lie in the middle of the valve and must have on each side of it a valve-face, equal to one port plus half a lap.

Question 382—How large must the lap be on a valve which is required for a certain early cut-off?

Answer—The lap must be as long as that part of the traveling way of the valve that must be made after the cut-off has taken place.

Question 383—How must the D lap-valve be placed on the chest-face when the engine is in a dead line?

Answer—In this position of the engine the lap must extend over that steam port that is farthest away from the piston, as shown in Figure 189, on page 185.

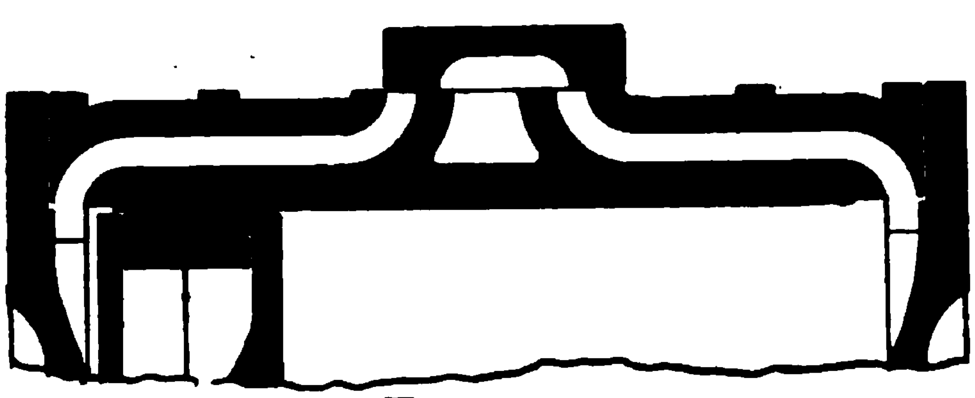


FIG. 189.

Question 384—How large must the throw of an eccentric be, or the stroke of a valve-crank, in order to operate a D lap-valve in an engine?

Answer—As we explained before, the lap must extend over that port which is farthest off from the piston when the engine

lies in dead line. Consequently, there is necessary, not only a traveling way that is equal to twice the width of a steam port, but at each stroke we have to bring the lap from one side to the other, over the respective port; therefore, the traveling way of the D lap-valve is necessarily equal to twice the width of a steam port plus the lap, consequently the throw of the eccentric or the stroke of the valve-crank regulating it must also be equal to twice the distance between the two centers of eccentric as well as crank; we must construct the eccentric as well as the valve-crank so that the distance between their two centers is equal to one port and a half a lap.

Fig. 190.

Fig. 191.

Question 385—In what position must the eccentric or valve-crank be placed with reference to the engine-crank in order to operate a D lap-valve?

Answer—We know that when the great radius of an eccentric or the middle line of a valve-crank is at right angles to the middle line of the engine-crank, the valve lies with its ends at equal distances from the center of its seat. Consequently, with the great radius of an eccentric or the middle line of a valve-crank placed in this way, the engine-crank would stand at right angles to the middle lines of these contrivances, which set the valve in motion, and half a lap would extend each side of the port, as shown by Figure 190. Now while this would be in violation of the rule given, because when the engine is in dead line the steam port that is nearest the piston must be ready to open at once and must bring the acting point, which is the center of the valve-crank wrist-pin, or the center of the eccentric, out of plumb to the extent of half a lap in the direction that the engine runs. Consequently, the position of the valve and eccentric must be as illustrated in Figure 191.

Question 386—At what angle should the great radius of an eccentric or the middle line of a valve-crank stand to the middle line of the engine-crank in an early cut-off engine?

Answer—When the engine has a direct-acting valve-gear, the angle would be obtuse, but acute if the valve-gear is an indirect-acting one.

Question 387—What is a right, an obtuse and an acute angle?

Answer—When two lines intersect each other so that the four angles formed are equal, we call each of them a right angle; if two lines form an angle that includes a larger space than that included in a right angle, we call it obtuse, and if the space included is smaller, we call it acute.

Question 388—How should the rocker be set on an early cut-off engine?

Answer—The engine should be placed out of dead line so that the great radius of the eccentric or middle line of the valve-crank, as the case may be, would stand in plumb to the dead line then the rocker should also be set in plumb to the dead line, when it will be seen that the great radius of the eccentric, or the middle line of the valve-crank, as the case may be, is parallel with the rocker; then the eccentric or the valve-crank should be connected to the lower rocker-arm.

Question 389—How can the position of the great radius with reference to the engine-crank be decided for any kind of cut-off?

Answer—The crank wrist-pin travels through a circle, and when it starts with a stroke it travels through a part of the circle up to the moment that the cut-off takes place. If we divide this part of the circle by half and draw through the point that indicates the middle, a line parallel with the dead line, this parallel line will intersect the circle through which the crank wrist-pin travels, and if we connect this point of intersection with the center of the shaft by a straight line, this will indicate the correct position of the great radius for the required cut-off. From the time that the crank wrist-pin starts the stroke, up to the moment when the cut-off takes place, the steam port must be opened and closed, and, therefore, half the traveling way of the wrist-pin is represented in passing through the width of the port. Of the three dia-

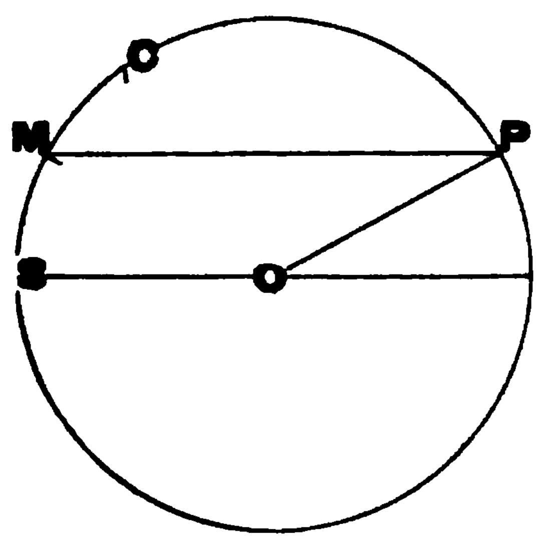


FIG. 192.

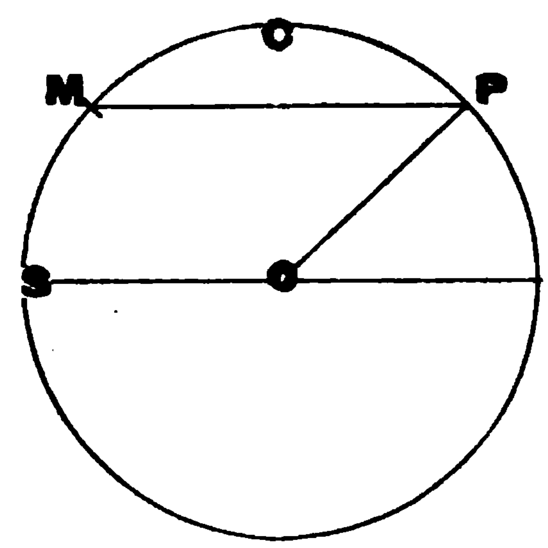


FIG. 193.

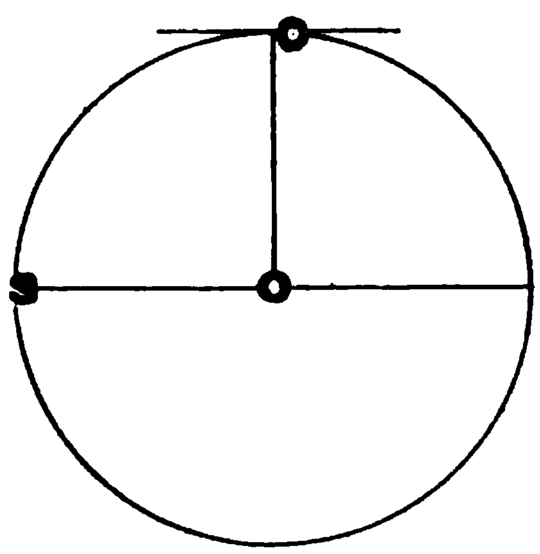


FIG. 194.

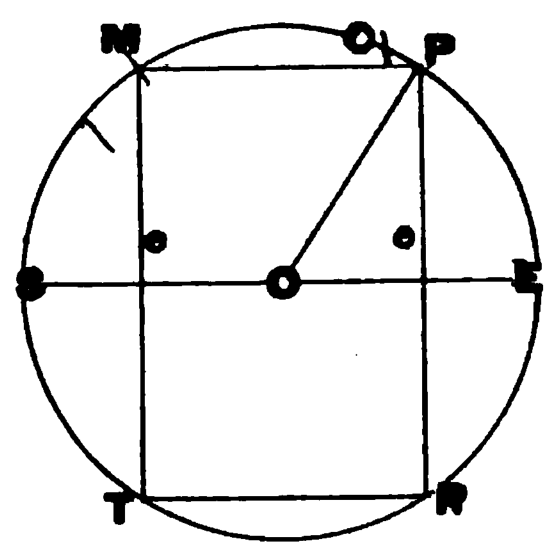


FIG. 195.

grams, Figures 192, 193, and 194, Figure 192 represents an early cut-off, Figure 193 a later one and Figure 194 a common cut-off. In these three figures S represents the points at which the crank wrist-pin lies at the beginning of a stroke, C the point at which the wrist-pin has arrived when the cut-off takes place, M a point midway between C and S, through which is drawn a line parallel to the dead line, and this touches the circle at the point P, so the line PO represents the

position of the great radius with reference to the crank which lies in the direction of OS.

Question 390—Can you explain, by diagram, the parts of the circle through which the crank wrist-pin travels while the steam port is opened and the expansion takes place?

Answer—In Figure 195, which represents the dead line, SO indicates the position of the crank at the beginning of the stroke, C the point at which the cut-off takes place, M a point midway between S and C; MP a line parallel to the dead line, SE and OP the position of the great radius at the start of the stroke; OE indicates the position of the great radius if the steam port is wide open and OR its position when the cut-off takes place during the first stroke; OT will be the position of the great radius if the second stroke starts; SO when the steam port is wide open, OM when the steam port is closed and the cut-off takes place. Consequently, Se and Ee, represent the parts of the stroke during which a steam port will be opened or closed, and *ee* the part of a stroke during which expansion takes place in the cylinder.

Question 391—How can you decide as to what position the crank wrist-pin should occupy when a certain cut-off takes place in an engine?

Answer—In the diagram Figure 196, the lengths AA-1, BB-1, CC-1, DD-1 and EE-1, represent the length of the connection-rod; AA-1 shows the connecting-rod while the engine is in dead line; BB-2 when quarter-stroke has been made; CC-2 when half-stroke has been made; DD-3 when three-quarter-stroke has been made and EE-1 when the stroke is complete. With circles B-1, B-2, C-1, C-2 or D-1, D-2, respectively drawn, then the position of the crank wrist-pin will be indicated by B-2 with quarter cut-off, by C-2 with half cut-off and by

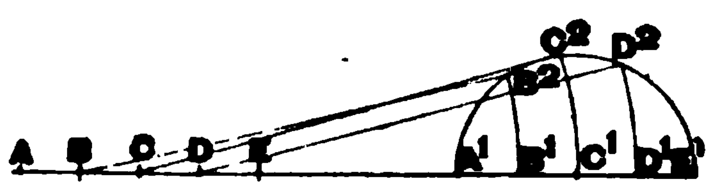


FIG. 196.

D-2 with three-quarters cut-off; so a circle drawn with a compass, opening equal to the length of the connecting-rod, through any point of the stroke with the center lying in the dead line, represents the position of the crank wrist-pin for the respective cut-off.

Question 392—In what position must the center of the eccentric be with reference to the engine-crank in an early cut-off engine?

Answer—The distance between the center of the eccentric and the center of the shaft must be equal to the width of one steam port plus half a lap, and the center of the eccentric must fall out of plumb to the extent of half a lap. In Figure 197 SO represents the position of the engine-crank, O being the center of the shaft, and S the center of the wrist-pin. With OL representing the width of a steam port placed in the position of the great radius PO, and OR represents a line vertical to the shaft in O, we must find a point which represents the center of the eccentric. Now, if the distance vertically from M to OR, which is MN, is equal in distance between L and M, then the point M is bound to be the center of the eccentric. LM, as well as MN, must be half a lap to satisfy the condition of the rule.

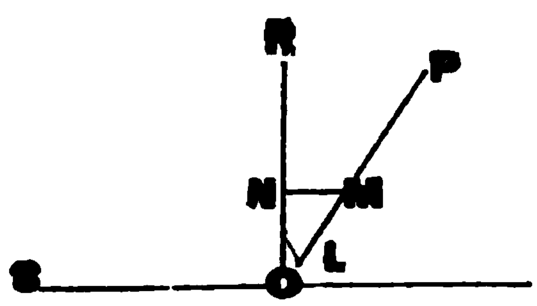


FIG. 197.

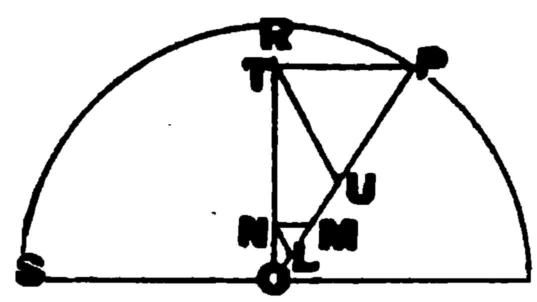


FIG. 198.

Question 393—How can the position of the center of the eccentric be distinguished in the great radius, the position of which is given to the crank for a certain cut-off?

Answer—In Figure 198 SO represents the position of the engine-crank, OP the position of the great radius, RO a vertical line to SO, and PT a line at a right angle to RO. Now we place the distance PT on the great radius as PU and draw the line TU, the triangle TPU is equilateral, consequently the angle PTU is equal to the angle PUT. Now, if we place the width of a steam port of the steam cylinder on the line OP, representing the position of the great radius as OL, and draw through L a line parallel with TU, intersecting OP in N, and a line through N parallel with PT, we find by NM the distance for which the center M of the eccentric must fall out of plumb to the crank, because NM is equal to LM, equal to half the lap, while NML is also an equilateral triangle on account of the fact that NL is parallel to TU and NM parallel to TP.

Question 394—Can we make any kind of cut-off with a D lap-valve?

Answer—No; the cut-off that can be made with advantage is limited; a cut-off earlier than three-fourths cannot be made with advantage by a D lap-valve.

Question 395—What is the reason that a D lap-valve cannot make with advantage an earlier cut-off than a three-quarter?

Answer—Whenever a D lap-valve is used, its exhaust cavity can by no means be made larger than four times the width of a steam port, because if so constructed, when in the center of its travel, the steam on both sides of the piston would exhaust, as illustrated in Figure 199, page 191. Therefore, the exhaust cavity must be slightly diminished in size and amount, for which it is made smaller than in the common D valve, and called the inside lap of the valve in contradistinction to the outside lap, which elongates the D lap-valve in as far as its length exceeds that of the common D valve. But by shortening the exhaust cavity of the D lap-valve, we cut off the exhaust too early and form a counteraction against

FIG. 199.

the driving steam, and even this is not the only drawback, because by the further motion of the valve, the driving steam exhausts before the stroke is completed. There is, consequently, no driving power acting on the piston, but opposite to it, the exhaust steam is compressed at the cost of power accumulated before in the fly-wheel. Figure 200 shows the position of the engine when the exhaust is stopped, Figure 201 when the driving steam is exhausting, and exhaust steam must be compressed.

Question 396—How must we arrange the valve-gear when the valve stands under the control of an eccentric or a valve-crank, and we desire to make an earlier cut-off than a three-quarter?

Answer—We must use for this purpose two valves, one of which is to regulate the exhaust and the other the expansion. Therefore, we use one valve with an exhaust cavity and the other without one. The valve that we use without an exhaust cavity is called a lap-valve. Such a valve with an exhaust cavity, and a lap-valve may be used together in one steam-chest, or we may use two lap-valves of which the one acts in

a steam-chest and the other in an exhaust-chest. For the first two constructions the steam cylinder can be used as explained before, but for the last-named construction the steam cylinder requires change in its construction.

FIG. 200.

FIG. 201.

Question 397—How do you construct a valve-gear (valves being connected to eccentrics or valve-cranks) for an earlier cut-off than a three-quarter, when using two valves, acting in one and the same steam-chest?

Answer—In Figure 202 such arrangement is illustrated. The valve A represents the exhaust-valve, the valve B the expansion valve. The exhaust-valve is constructed like the common D valve, but it is made with elongations on its side that

are perforated in the size of the steam port indicated in figure by *aa*. This valve is so arranged that its exhaust cavity, *a*-2, four times the width of a steam port, is lying in the middle of the valve. The valve-face is equal in length to ten times the width of the steam port, and is perforated on both sides by a passage equal in size to a steam port, which is midway between the exhaust cavity and the end of the valve. This valve is operated by an eccentric that has a throw of twice the width of a steam port, the great radius of which is at a right angle to the engine crank. The valve admits steam and allows the exhaust to pass freely during the whole stroke. But the passage in this valve can be closed by a lap-valve riding on it, so that the admission of steam to the cylinder is allowed only during a certain part of the stroke by the lap-valve riding on it, so that the admission of steam to the cylinder is allowable only during a certain part of the stroke by the lap valve, which in length is equal to six times the width of a steam port, plus the lap. This valve must be

FIG. 202.

opened by another eccentric, the throw of which is equal to twice the width of a steam port, plus the lap, and the center of it must fall out of plumb to the engine-crank to the extent of half a lap. The valve that regulates the exhaust is set so as to just cover the steam ports while the engine is in dead line, while at the same time the lap-valve extends its lap over that farthest away from the piston.

Question 398—How is a valve-gear constructed for an earlier than three-quarter cut-off, when the valves are connected to eccentrics or valve-cranks, and each of the two valves act in a separate steam-chest?

Answer—Figure 203 illustrates such a construction; A and B are two chests, one lying on top of the other; A communicates

with B by a port *a*, which is as wide as a port in the steam cylinder, and B communicates with the steam cylinder, which is constructed in the common way by the ports *b*-1 and *b*-2. In the chest A a lap-valve L, which is in length equal to once the width of a steam port plus the lap, acts as is required for the desired early cut-off; this valve is mounted on the chest-face so that the lap reaches over that side of the port which is farthest away from the piston when the engine is in dead

FIG. 203.

line, and it must be operated by an eccentric, the throw of which is equal to twice the width of a steam port plus the lap, and the center of which falls out of plumb to the engine-crank to the extent of half a lap. In the chest B acts a common D-valve V which must cover equally the steam ports, when the engine is in dead line, and which is operated by an eccentric with a throw equal to twice the width of a steam port, the great radius of which stands at a right angle to the engine-crank.

Question 399—How must the valve-gear be arranged for an earlier than three-quarter cut-off, when the valve must act in connection with eccentrics or valve-cranks, and the one valve must operate in a steam-chest, while the other operates in an exhaust chest?

Answer—The construction of such a valve-gear is illustrated in Figure 204, A representing the steam-chest and B the exhaust chest. L is the valve that admits steam to the steam-cylinder and E the valve which allows the discharge of the same from it. The steam-cylinder is, not only in regards to the steam-chests, different from all others hitherto described, but it has for each chest only two ports which stand apart, separated by a steam bridge equal in width to a steam port. The valves have no exhaust cavities; the valve B is a lap-valve, the lap

of which lies over that port which is farthest from the piston, while the engine is in dead line, and the eccentric by which it is operated, must have a throw equal to twice the width of a steam port plus the lap, and its radius with the center of

FIG. 204.

the eccentric should fall out of plumb to the engine-crank to the extent of half a lap, in the direction the engine must run. The exhaust-valve E must be a self-balancing slide-valve, covering both ports equally when the engine is in dead line, and the eccentric by which it is operated must have a throw equal to twice the width of a port and must stand with its radius at a right angle to the engine-crank, but in an opposite direction from that in which the engine is running.

Question 400—Does the extent of the throw of an eccentric exert an influence upon the setting of the lap?

Answer—The setting of a lap does not depend on the throw of an eccentric; it is dependent only upon the extent to which the center of the eccentric is set out of plumb to the engine-crank.

Question 401—If the throw of an eccentric is not sufficient according to the lap set, what influence will that have on an engine?

Answer—The steam port cannot be entirely opened, and the steam will consequently be wire-drawn.

Question 402—Does the size of the lap on a valve depend only on the kind of early cut-off?

Answer—The size of lap depends, not only on the kind of early cut-off, but, also, on the width of the steam port and on the ratio between the connecting-rod and the engine-crank.

Question 403—What should be the ratio between the connecting rod and the engine-crank?

Answer—The ratio between the length of the connecting-rod and the length of crank should be 5 to 1. The shorter a connecting-rod is made, the more power is lost by transferring the straight motion of the piston-rod into the rotary one of the crank-shaft.

Question 404—What has the width of a steam-port to do with the length of the lap for a certain early cut-off?

Answer—The wider the steam-port is, the longer will be the lap.

Question 405—How can the ratio between the connecting-rod and engine-crank influence the lap for a certain early cut-off?

Answer—The more the connecting-rod is shortened as compared to the engine-crank, the longer will be the lap.

Question 406—By constructing a valve-gear, in which the valve is in permanent connection with an eccentric or valve-crank, what may hinder or prevent us from making an early cut-off?

Answer—From the foregoing we have learned that the earlier the cut-off, the wider the steam port, or the shorter the connecting-rod, as compared to the crank, the longer will be the lap. The lap should not make the valve so long that the travel of the latter requires a steam-chest longer than the cylinder. We should also recollect that the longer the valve, the more power is lost by friction.

Question 407—How must the steam cylinder and the valve be constructed, in order that the engine will work under an early cut-off, while the valve is controlled by a cam?

Answer—The valve that is to be used in connection with a cam is of the same shape as the common D-valve, being equal in length to six times the width of the steam port and having an exhaust cavity of four times the width of a steam port; but the steam cylinder shows in its chest-face three openings of equal width; the steam bridges between are of the same width; the exhaust port is, consequently, equal to the width of a steam port. The cylinder must be changed in this way, otherwise the valve would get too long and cause unnecessary friction.

Question 408—How must the cam be constructed to regulate an early cut-off in an engine?

Answer—To make a construction for such a cam we use four circles, concentric with the shaft, which stand at distances from each other of the width of a steam port. The diameter of the inner circle equals one and one-fourth the diameter of the shaft. These concentric circles are marked in Figure 205, page 197, in a row, thus: 1, 2, 3, 4, so that the inner

circle is 1. In Figure 206, on the same page, the positions of the valve are indicated by the same figures as the circles against which the cam-rod acts reciprocally. The position of the crank is marked with OS. In the same plane with the crank, is the middle line of the cam, which must be set with the crank in one and the same plane. When the engine is in dead line, the cam-rod must act against the circle 2 or 3.

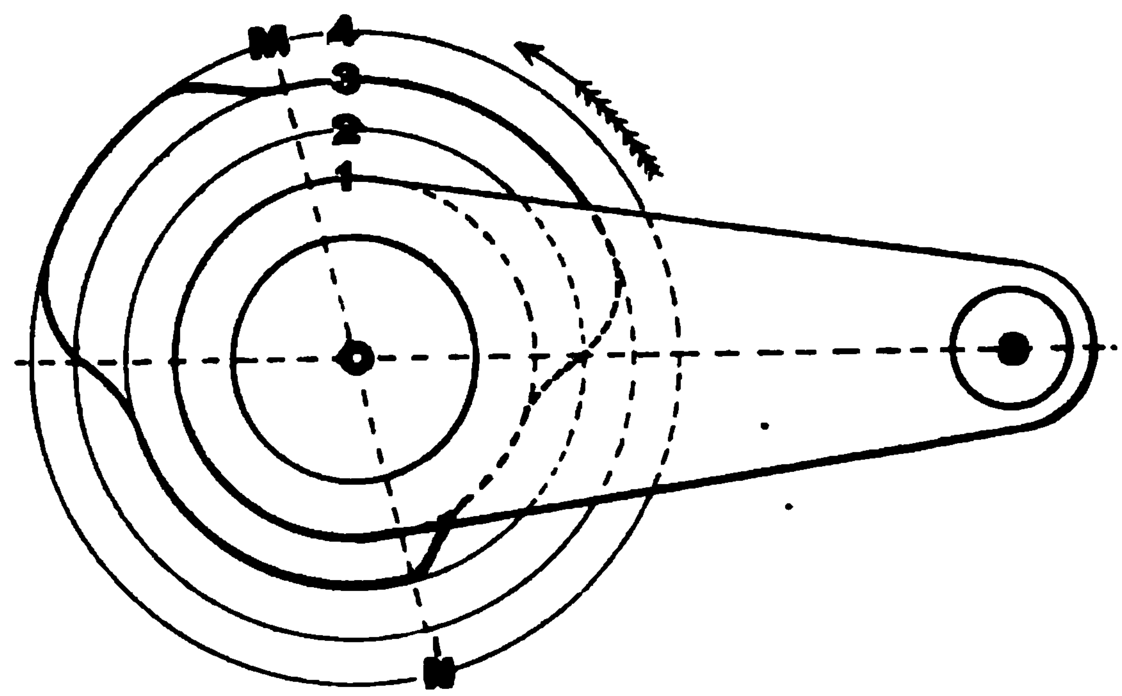


FIG. 205.

When the port is open, the cam-rod must act against the circle 1 or 4. The same angle that the crank makes with the dead line in the moment that the early cut-off takes place we mark as a diameter in the diagram as a line MN. When the engine is in dead line and the cam-rod acts against circular line 2, the valve must next come in position 1. The consequence is that from the middle line the cam must taper off towards the circular line number 1. While the cam-rod is on

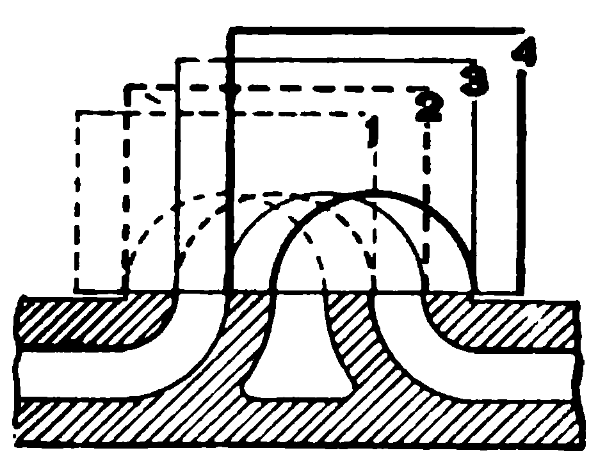


FIG. 206.

the circle number 4, the first port is open. The port stays open as long as the cam-rod rests against circular line 4, but when the cut-off takes place the cam must bevel off toward the circular line 3, meeting the line MN. The front port is

closed now, and expansion takes place as long as the cam-rod rests against circular line 3. A short time before the crank comes in dead line again, the cam bevels off toward the circular line 2, meeting that line at exactly the moment that the engine is in dead line. As soon as the second stroke starts, the cam-rod is brought in connection with the circular line 1. The cam is, consequently, beveled off towards the circular line 1, and brings the line in position number 1. Consequently, admitting steam to the cylinder, and until the line MN comes to the position of the dead line. At this moment the cut-off takes place again, and consequently, a short time

FIG. 207.

FIG. 208.

before the cam is beveling towards the circular line 2. The cam-rod which is now resting against the circular line 2, keeps the valve in position in number 2. But the cam bevels off again toward the circular line 3, a short time before the crank comes in dead line again. By studying the illustrations 207, 208, 209, 210, and 210a, it will be seen that not only during the time that steam is being admitted to the cylinder, but, also, during the time in which expansion takes place, the exhaust steam is allowed to escape.

FIG. 209.

FIG. 210.

FIG. 210a.

Question 409—Can a very early cut-off be made on an engine with a cam valve-gear?

Answer—With a cam valve-gear an earlier cut-off than half can be made, but if we go to the extreme, too far below this fraction of cut-off or stroke, the steam will be wire-drawn.

Question 410—What is understood by "A Stationary, Early Cut-Off?"

Answer—If an engine is constructed for a certain early cut-off, which it must work continually, it is called a stationary, early cut-off engine.

Question 411—What is understood by "An Adjustable, Early Cut-Off?"

Answer—When an engine can be changed from its cut-off while it is at rest, into another cut-off, but must then run under this cut-off until it is brought to rest again to have the cut-off changed, we call it an adjustable, early cut-off engine.

Question 412—What is understood by "A Variable, Early Cut-Off Engine?"

Answer—When an engineer is able to change the cut-off of an engine at any moment, without bringing the engine to rest, we call the engine a variable, early cut-off engine.

Question 413—What is understood by an "Automatic, Early Cut-Off Engine?"

Answer—One in which the point of cut-off is varied automatically by a governor in proportion to the fluctuations of the load on the engine.

Question 414—How do you place the great radius of an eccentric at right angles to the engine-crank?

Answer—We make, at equal distances, from the circumference of the eccentric, as well as of the bore, gauge and center marks, in four different directions. After we inserted into the bore of the eccentric a piece of board, we find, by means of a pair of dividers, the center of the bore, as well as that of the eccentric. Figure 211 shows us, in diagram, the gauge-marks and center points, as well on bore as on eccentric and also the way in which center and ex-center are found. Through these two points, which indicate center and ex-center, we draw a straight line with a scratching needle. In this diameter lies the great radius, which must be set at a right angle to the engine-crank. To do this, we place the shaft, by means of a spirit-level, in a horizontal

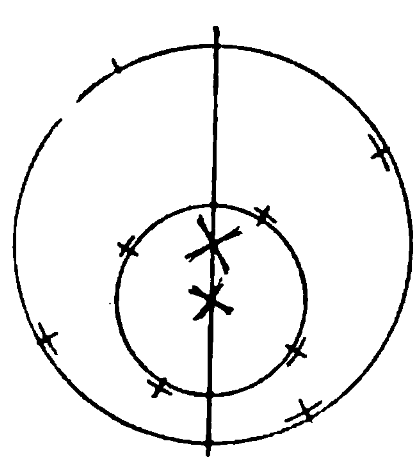


FIG. 211.

position, mount below the shaft a face-plate level, and by means of a face-gauge, take the distance vertically between the center of the shaft and turn the shaft until the face-gauge shows the center of the wrist-pin at the same height as the center of the shaft lies away from the face-plate; now we have the engine-crank in a horizontal position. If we then move the eccentric, which had been placed on the shaft before until the plumb line sights the great radius, then we have it at right angles to the crank.

Question 415—How do we place an eccentric with its center out of plumb to the crank, so that it forms with it, according to circumstances, an obtuse or acute angle?

Answer—After finding the center and ex-center, and drawing the great radius, we describe a circle with a compass, opening at equal distances between center and eccentric around the ex-center, as diagram 212 will show. Then we draw lines parallel with the great radius at a distance from it equal to half the required lap, and through the point where these parallel lines intersect the circle drawn, and through the center of the shaft, we draw straight lines. These lines are marked in the diagram with X and Y. One of these lines must now be placed in plumb to the engine-crank as before described.

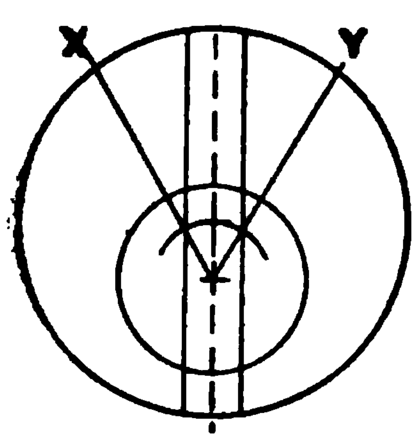


FIG. 212.

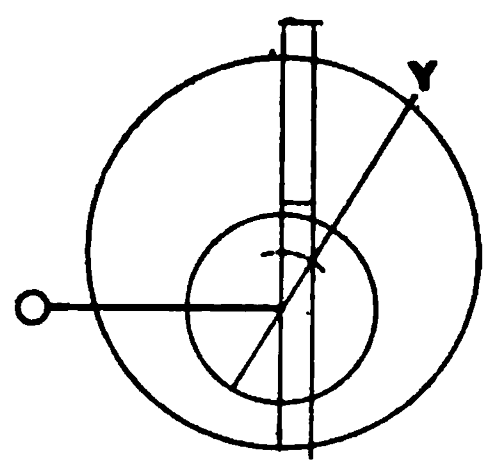


FIG. 213.

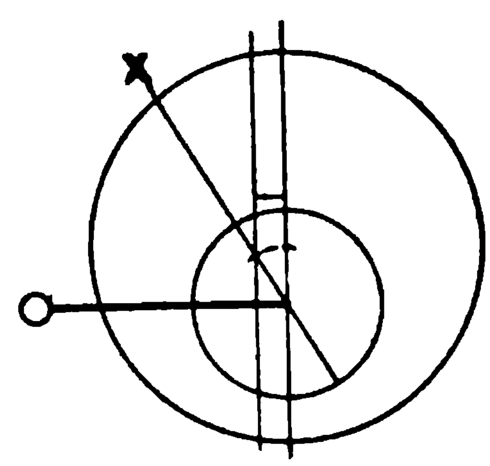


FIG. 214.

If the great radius forms an obtuse angle with the crank, we set that line which runs nearest to the crank at right angles to it, and if the great radius forms an acute angle with the crank, as will be necessary for indirect valve-gear, then we set in plumb to the crank that line which lies away from it. Figures 213 and 214 show the eccentric thus set to the engine-crank. Figure 213 is for a direct valve-gear and Figure 214 for an indirect valve-gear.

Question 416—What conditions must be complied with that an engine may be in line?

Answer—The crank-shaft must be level, the axis of the cylinder must lie at right angles to the axis of the shaft, and the axis

of the cylinder and axis of the shaft must lie in one and the same plane.

Question 417—How do you draw a cylinder line to represent the axis of a cylinder in a horizontal or inclined engine?

Answer—We leave the crank-shaft in the pillow-block boxes, but take the connecting-rod, cross-head and back cylinder head off, and take the piston with the piston-rod out of the cylinder. Then we make, in four different directions, gauge-marks, with center-points parallel to the counter-bore on the back cylinder flange. Then we insert a board tightly in back of the cylinder bore, so that it sets flush with the cylinder flanges, and find, by means of a pair of dividers and the before mentioned center points, the center of the counter-bore on this board. Carve out the wood, above the center, in a V-shape, so that its vertex is formed at the center of the counter-bore. Next carve out the wood, so as to form an incline toward the inside of the cylinder, ending in a sharp corner at the center of the counter-bore. Then we wind a fine, but strong silk string around one of the stud-bolts in the back cylinder-flange, and lay it over the center of the counter-bore and draw it through the cylinder toward the front end of the engine-bed. Here the string must be mounted on a pair of wooden wedges that will allow it to be either raised, or lowered, pushed to one or the other side, or otherwise operated, as may be required. Then with this string establish a point from which, in four different directions, the distance from the cylinder-bore, or the bore of the stuffing-box, will be the same. In determining this measure an hemaphrodized caliper, such as that illustrated in Figure 215, may be used.

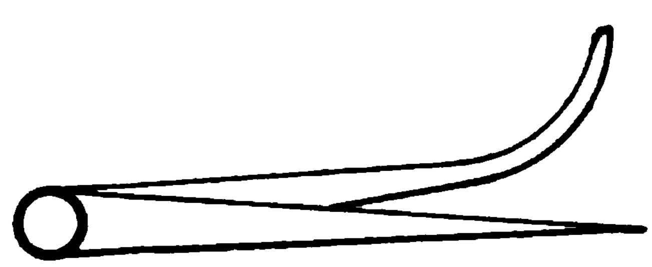


FIG. 215.

Question 418—How can we determine that the cylinder line and the axis of the shaft are not lying at right angles to each other?

Answer—When the cylinder line is drawn, the crank wrist-pin is left lying below it, and if then the crank is turned in the two opposite directions, until it just touches the cylinder line, and

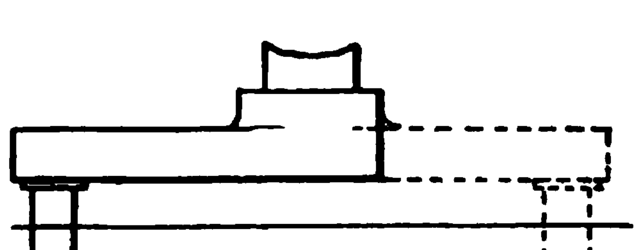


FIG. 216.

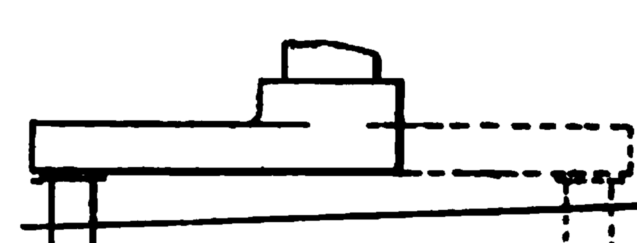


FIG. 217.

the distance between it and the shoulder of the wrist-pin is the same on both sides, the shaft lies at right angles to the cylinder line. Figure 216 shows the shaft in right, and Figure 217 in wrong position. The full lines show the wrist-pin in one direction, while the dotted lines show it in the opposite direction.

Question 419—What must be done if the crank-shaft does not lie at right angles within the cylinder line?

Answer—We are not privileged to move the front pillow-block box, in order to change the clearance of the cylinder, but must correct by moving the outer, or tail pillow-block box.

Question 420—In what way can we prove that the shaft lies level?

Answer—A plumb line should be dropped near the fly-wheel and the crank-shaft, as shown in Figures 218 and 219, a chalk mark made on the rim of the fly-wheel at a point nearest to the plumb-line, and the distance between it and the fly-wheel

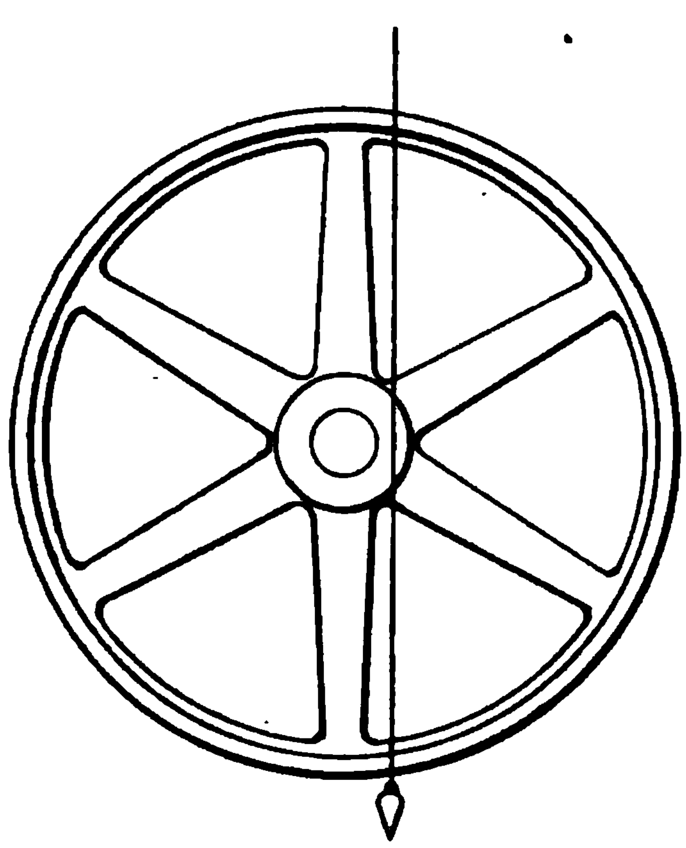


FIG. 218.

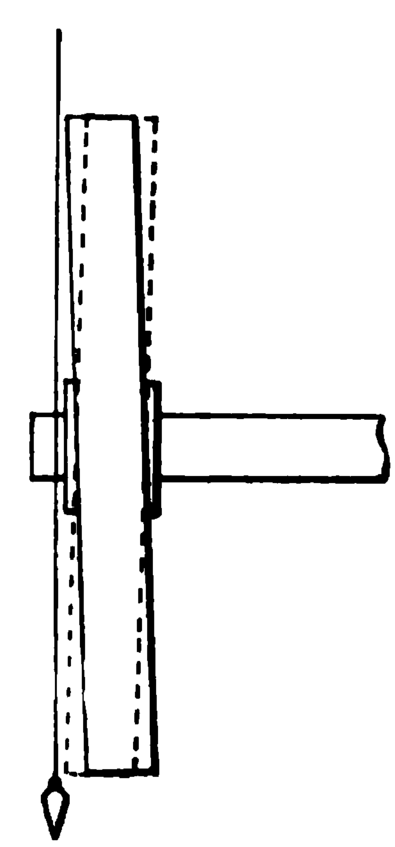


FIG. 219.

measured; if the fly-wheel be turned then, until the chalk-mark comes again nearest to the plumb-line, and if the same distance is found as before, the crank-shaft is perfectly level. It is quite immaterial whether the fly-wheel runs true or not, because each single point of a fly-wheel must rotate in a plane that stands vertically to the shaft. Another way to determine whether a crank-shaft is level, is to drop in front of it a plumb line, then move the shaft in opposite directions, until the crank wrist-pin touches the plumb-line, and if in both positions, the distance between the plumb-line and the shoulder of the crank wrist-pin is equal, the shaft is lying level.

The latter method cannot produce as accurate results as the former, because vertically the distance between the points at which the measure is taken, is at the crank wrist-pin a great deal smaller than at the fly-wheel.

Question 421—How can it be determined that the cylinder line and the axis of a shaft are both lying upon the same plane?

Answer—The engine-crank must be placed with the center of its wrist-pin plumb above and below the center of the crank-shaft, and the distance between the wrist-pin and the cylinder line in both positions, measured if these distances are equal,

FIG. 220.

FIG. 221.

both the axis of shaft and the axis of cylinder lie upon the same plane. Figure 220 shows both in right position, Figure 221 in wrong position; the full lines show the wrist-pin below the cylinder line, and the dotted lines above it.

Question 422—How should a cylinder line be drawn to represent the axis of the steam cylinder in a vertical engine?

Answer—A plumb-bob should be suspended, passing through the cylinder of a vertical engine, so that the measure taken in four different directions at front and back bore proves equal in each direction; then the cylinder is in correct position; if the distance in different directions varies at the top or the bottom the position of the cylinder must be corrected. To steady the plumb-bob for the purpose, it is advisable to place it in a cup filled with a liquid of a great consistency, such as heavy cylinder oil, or molasses.

Question 423—How do you determine the right length of a connecting rod in use on an engine?

Answer—To do this, we take the back cylinder head, the cross-head, and connecting rod of the engine, and piston with piston rod out of the cylinder. Then measure the distance from the back flange of the steam cylinder to the inside of

the front cylinder head; subtract from this, first the hub of the back cylinder head, which extends into the counter-bore, second the width of the piston, and third the stroke of the crank. The remainder will be the clearance, half of which is set to each side between piston and cylinder head by each stroke. We then insert the piston with piston rod into the cylinder, and fasten the cross-head to the latter, and push the piston into the cylinder, so that between it and the flange of the back cylinder head, there is left a distance equal to the hub of the back cylinder head plus half the clearance. Then we bring the engine-crank in dead line, lying towards the cylinder, and measure the distances between the centers of the crank wrist-pin and the cross-head wrist-pin; this distance must correspond with the distance between the centers of the brasses of the connecting rod.

Question 424—How do we find the length of a valve-rod?

Answer—If the link of the valve-rod extends far enough from the stuffing box of a steam chest to allow a repacking, we measure from that point as the center of the link towards the valve while it is standing in the position it must occupy when the engine is in dead line and a steam port is ready to open. Or if the engine stands in dead line, and the valve is placed in due position, we bring the center of the link of the eccentric rod to the middle line of the stuffing box of the steam chest, and from the center of this link towards the valve, take the measure for the length of the valve-rod.

Question 425—How do we find the right length of the eccentric rod?

Answer—If the engine is in dead line, and the valve in due position, we measure from the center of the link of the valve-rod towards the center of the eccentric.

Question 426—What must be included in an order for an eccentric?

Answer—We must include the diameter of the eccentric, also the diameter of the shaft, and the distance between the two centers.

Question 427—If the steam ports in a steam cylinder of an engine are half an inch wide, and the expansion valve has a lap of an inch and a quarter in length, and the shaft of the engine is four inches in diameter, how do you give an order for the two eccentrics required for the riding valves?

Answer—The throw of the eccentric for the full pressure valve is twice the width of a steam port, consequently one inch; the eccentric for this valve must be of a diameter, equal to $1\frac{1}{2}$ times the shaft plus the throw$=(1\frac{1}{2}\times4)+1=6+1=7$ inches.

The distance between the two centers is half the throw=$\frac{1}{2}$ inch. Consequently the order we must give for the full pressure eccentric is: Diameter of shaft 4 inches, diameter of eccentric 7 inches, distance between centers $\frac{1}{2}$ inch. The throw of the eccentric for the expansion valve must be equal to twice the width of a steam port plus the lap; this amounts to $\frac{1}{2}+\frac{1}{2}+1\frac{1}{4}=2\frac{1}{4}$ inches. Half the throw is $1\frac{1}{8}$ inches. The diameter of this eccentric must be $1\frac{1}{2}$ times the diameter of the shaft plus the throw; therefore $(1\frac{1}{2}\times 4)+2\frac{1}{4}=6+2\frac{1}{4}=8\frac{1}{4}$ inches. Therefore the order we must give for the expansion valve is: Diameter of eccentric $8\frac{1}{4}$ inches, diameter of shaft 4 inches, distance between the centers $1\frac{1}{8}$ inches.

Question 428—What difference in dimensions are we required to observe when using valve-cranks instead of eccentrics?

Answer—A valve-crank acts exactly like an eccentric, if the distance between their centers is the same, and if the position of the center of the wrist-pin with reference to the engine-crank is the same as that required for the center of the eccentric.

Question 429—In what position must a cross-head wrist-pin and a crank wrist-pin be?

Answer—Both must lie parallel to the crank-shaft.

Question 430—How do you ascertain that the wrist-pins on an engine are in due position?

Answer—If the connecting rod is joined to the crank wrist-pin, when the cylinder line is drawn, and varies from the cylinder line in two opposite positions, that is a proof that the crank wrist-pin is not parallel with the crank-shaft; but the crank must be set in two positions which will vary from each other about a right angle, and the trial must be made in both positions. If the center line or the crank wrist-pin lies parallel to the shaft, and we join the connecting rod to the cross-head wrist-pin, and it does not then fit between the shoulders of the crank wrist-pin, the cross-head wrist-pin does not lie parallel to the crank-shaft, provided the piston rod is in line; but this trial must be made once while the crank is lying in dead line, and once in a position vertical, or about so, to the dead line. Before this trial can be made, we have to be sure that the crank-shaft is lying level.

Question 431—Can we not be misled when trying to ascertain whether or not the wrist-pins are in right position, by the bore of the brasses which may not be plumb?

Answer—The irritation cannot take place, because if the connecting rod is falling, by its reverse, only to one side of the cylinder line, that shows us that the brasses are not bored plumb.

The two Figures 222 and 223 illustrate this. In Figure 222 the connecting rod crosses the cylinder line by being moved in two opposite positions; it shows that the wrist-pin is not

FIG. 222.

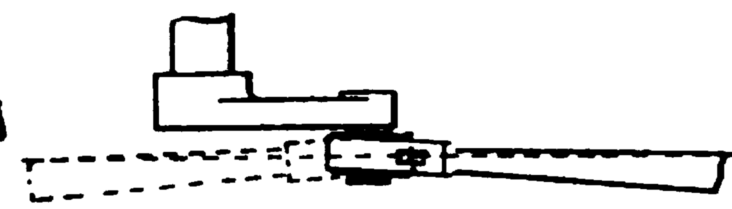


FIG. 223.

parallel to the crank. In Figure 223 the connecting rod falls both ways, only to one side of the cylinder line. That shows that the brasses are not in plumb.

Question 432—How do we find that the piston rod of an engine is lying in the center of the cylinder?

Answer—The guides of the piston rod must be placed at equal distances from the cylinder line, and the distances of the guide rods must, therefore, be measured with calipers therefore near the cylinder as well, as at their extreme ends, and not only at both sides of the cylinder line, but also underneath and above it.

Question 433—Are there substitutes for the main parts that constitute an engine?

Answer—For the steam cylinder, the crank-shaft and valve gear there are no substitutes, but we have them for the connecting rod and the fly wheel.

Question 434—What may be used as a substitute for the connecting rod in an engine?

Answer—There are two ways to substitute a connecting rod in an engine; the one way is shown in an engine that we call a yoke engine, and the other in one which we call the oscillating engine.

Question 435—How is a yoke engine constructed?

Answer—The cross-head of this engine has no stationary wrist-pin and is yoke shaped, having the crank wrist-pin sliding in the yoke. This engine cannot work without a fly wheel, because in the absence thereof the dead line cannot be broken. Figure 224 shows a yoke engine in dead line, Figure 225 when the rotary motion is started.

Question 436—How can an oscillating engine work without a connecting rod?

Answer—The cylinder of such an engine is not stationary as its name applies, it oscillates. When the piston is at the end of the stroke, the engine crank lies in the same line with the piston rod. This dead line must be broken by a fly wheel, and when this is done, a rotary motion takes place again, because the piston rod follows the crank wrist-pin to which it is directly joined by the brasses. The swinging point of the cylinder may be made at any point in its length or even on its end.

FIG. 224. FIG. 225.

Question 437—How does the valve gear act in a yoke engine?

Answer—In this engine the valve gear is composed of the valve, in connection either with a valve-crank, an eccentric, or cam. Thus it acts exactly like other engines, in which the valve is set in motion by the same contrivances.

Question 438—How does the valve gear act on an oscillating engine?

Answer—The valve in an oscillating engine may lie either permanently in the same place and only the motion of the cylinder may control the admission and discharge of steam as shown in Figures 226, 226a and 226b, or the valve may

follow the oscillating motion of the cylinder, being retarded or advanced by links, as will be seen in Figures 227, 227a and 227b.

Question 439.—How must we arrange an engine in which no fly wheel is required to break the dead line?

Answer—This is arranged in an engine that we call a twin engine; in this we use two steam cylinders in connection with one and the same shaft, which bears a crank for each

FIG. 226.

FIG. 226a.

FIG. 226b.

of the cylinders; and these cranks stand at right angles to each other. Or it can be arranged in an engine which we call a triple engine; in this we use three steam cylinders connected with a mutual shaft which bears three cranks, one for each cylinder, and these cranks stand around the shaft, having equal angles between each other. Still another engine is

FIG. 227.

FIG. 227a.

FIG. 227b.

used for the same purpose, which is called a quadruple engine. In it one mutual shaft bears four cranks that stand at right angles to each other, each crank acting in response to a single steam cylinder. In these engines, when one piston is at the end of the stroke, another one is always operated by steam pressure, so that by turns the cylinders help each other over the starting point and out of the dead line. In Figures 228 and 228a, a twin, in Figures 229 and 229a, a triple, and in Figure 230, a quadruple engine is illustrated.

Question 440—How does the valve gear act on a twin, a triple and a quadruple engine?

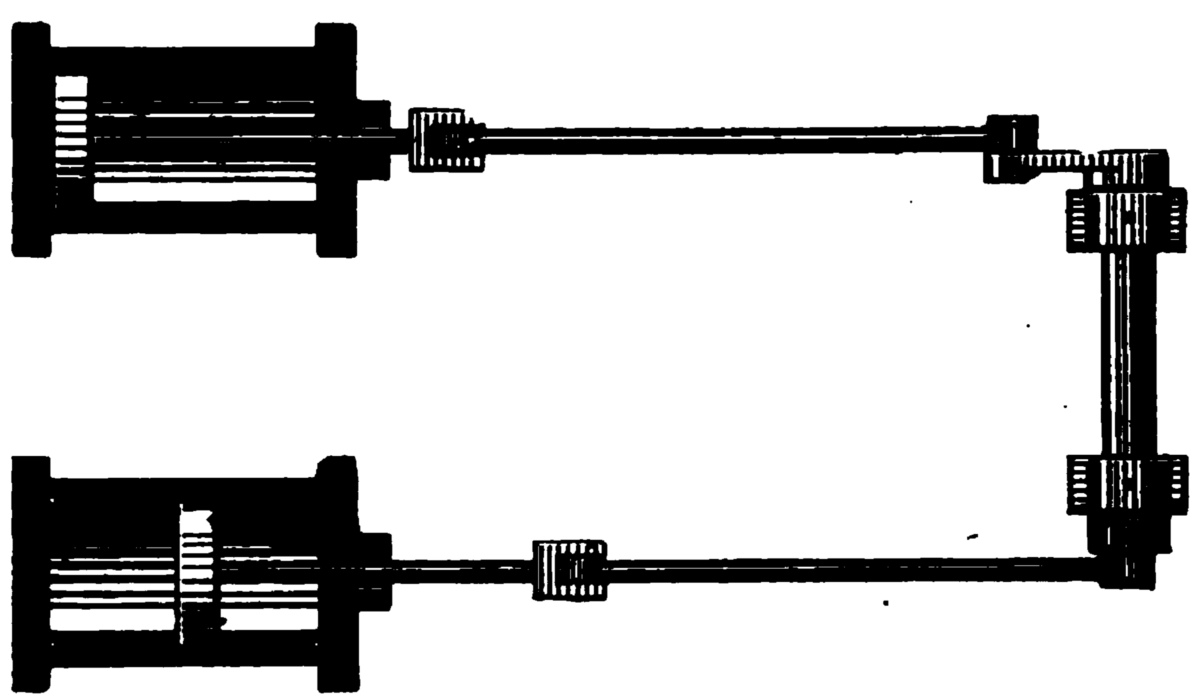


FIG. 228.

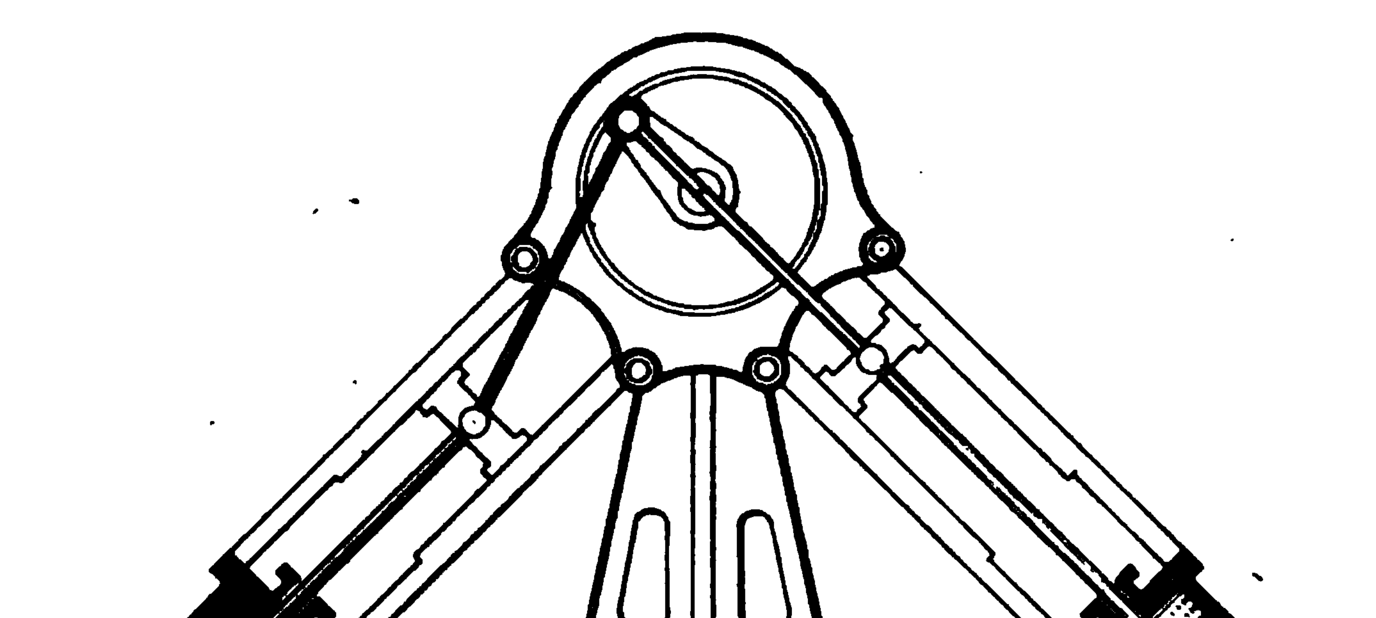


FIG. 228a.

Answer—Generally only eccentrics are used on this class of engines for the purpose of setting in motion the valves on the different steam cylinders, but cams and valve-cranks can be used also. Each steam cylinder requires its own valve gear, and this is constructed in the same way as that de-

FIG. 229.

FIG. 229a.

scribed for engines which have only a single cylinder. Each of the cylinders in these engines receives its steam direct from the boiler.

Question 441—Cannot twin, triple, and quadruple engines be constructed so that they may act in two different directions?
Answer—Yes, if they are provided with a link motion.

FIG. 230.

Question 442—How is a link motion constructed, and how does it act?
Answer—Figures 231 and 232 represent two different types of link motion as applied to a vertical engine. The first one is called the shifting link and is in general use on locomotives, marine engines, hoisting engines, etc. The second one is called the stationary link, it is seldom seen in the United States, but is largely used in Great Britain. Referring to Figure 231 the two eccentrics are mounted upon the crank shaft C; the eccentrics A and A1 are connected to the main link K by means of the two eccentric rods B and B1; the link block E which slides in the link K is connected to the valve by means of valve rod S; the link K is spanned by a plate called the saddle and the pin formed thereon is called the saddle pin. The link is held in position by means of the link hanger M, being connected at one end to the saddle pin and at the other to the short lever arm N. This lever arm and the reverse lever P are mounted upon the tumbling shaft O. In the figure the link is shown in full gear, that

means the entire influence of one of the eccentrics is thrown upon the valve. In the figure eccentric A is in action, the pin of the eccentric rod B being in line with the link block and by examining the position of the eccentric A it will be found that the engine must run in the direction the arrow points. If it is desired to reverse the engine the reverse lever P is moved to the opposite end of the notched segment Q; this places the pin of eccentric rod B1 in line with the link block, which throws the entire influence of eccentric A1 upon the valve causing the engine to run in the opposite direction. The

FIG. 231.

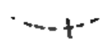


FIG. 232.

valve is provided with a lap and the center of the eccentrics are set accordingly in advance as explained in valve motion; but if a still earlier cut-off is desired the lever P may be placed at any point between the end and center notch, this reduces the influence of one eccentric and increases that of the other consequently reducing the travel of the valve and thereby causing an earlier cut-off. To set the valve on an engine provided with a link motion we place the lever P in the extreme end notch of the segment Q, turn the engine in the direction it should run and stop at the front dead center. This being done we notice the position of the valve and find it shows $\frac{1}{8}$ in. lap, for instance: then we turn the engine again and stop at the opposite dead center and the valve, we will assume, shows 3/16" lead, 3/16"+1/8=10/32 ÷2=5/32. The lead being, at the back port we must lengthen the eccentric rod 5/32 inch, and we mark on the respective eccentric rod, lengthen 5/32 inch.

Next we place the reverse lever at the opposite end of the notched segment, turning the engine in the opposite direction and stop at the front center. The valve shows 1/4 inch lead and on the back center 1/8 inch lap; for instance: 1/4 +1/8= 6/16÷2=3/16. The lead being at the front port we must shorten the eccentric rod, and therefore mark on the eccentric rod shorten 3/16". Now, we make the adjustments. In the first operation we had 1/8 inch lap at the front port and 3/16 inch lead at the back port. Subtracting 5/32 inch from 1/8 inch lap leaves 1/32 inch lead, and adding 5/32 inch to 3/16 inch lead still leaves 1/32 inch lead, showing 1/32" lead on both sides, which is about right.

The other eccentric rod we must shorten 3/16 inch; here we had 1/4 inch lead and 1/8 inch lap. After the adjustment is made we find that we have a lead of 1/16 inch on both sides, which is evidently too much.

To reduce the lead we loosen the set screws of that eccentric and move it back until we have the desired lead.

Question 443—What regulates the speed of an engine?

Answer—The fly wheel regulates the speed of an engine, because without any fly wheel the power that is accumulated therein acts very irregularly and is transferred to other machinery with equal speed only by the fly wheel.

Question 444—What regulates the steam power that is used in an engine?

Answer—We are able to regulate the steam power that is used in an engine by opening or closing, more or less, the throttle valve that is used principally in starting and stopping it. But it can be regulated automatically by a governor.

Question 445—What kind of governors are most in use?

Answer—The most popular governors are the rotary pendulum governors, and the shaft governor, often called the fly wheel governor.

Question 446—What is a pendulum?

Answer—A pendulum is made by a weight hanging on a light string or rod, and suspended to a stationary point, on which it oscillates. We have two kinds of pendulums: the suspending point in the one is in the same plan in which its weight swings, and this is called a straight or simple pendulum; then we have another one in which the suspending point of the weight is not in the same plan in which the weight swings; this is called the rotary pendulum.

Question 447—What is the action of a simple or straight pendulum, and how can it be measured?

Answer—A straight pendulum must be measured by the distance that lies between the suspending point and the point of gravity of its weight. When a pendulum is equal in length to one meter, it makes a swing in one second's time. A meter is equal to 39.37 of an inch. If the pendulum varies from this size, the time that is required for a swing will vary accordingly, producing, consequently, a variation in the number of swings which the pendulum makes in a second. If the length of the pendulum is expressed in meters, either by a multitude of meters or by a fraction of one meter, the time, measured in seconds, in which one swing takes place is equal to the square of its length. Consequently, if the pendulum is a half a meter long, it takes a half times a half, equal to one-quarter of a second's time for one swing; if it is a quarter meter long, it takes a quarter times a quarter, equal to one-sixteenth of a second, for one swing; if the pendulum is two meters long it takes $2 \times 2 = 4$ seconds to one swing. If it is six meters long it will take $6 \times 6 = 36$ seconds to one swing. The amount of weight that is carried by the pendulum has no influence upon the time of a swing, but the lighter the weight the longer the swing will be.

Question 448—How is the length of a rotary pendulum measured, and what is its action?

Answer—Figure 233 shows the oval ("A") or circular plan in which the point of gravity of the weight "B" swings; "C" is the suspending point, the line "BB" is the diameter of the circular plan, and the line "CD" shows the height of the cone which the pendulum describes by its rotation. The length of a rotary pendulum cannot be measured by the distance between its suspending point and the point of gravity of its

weight, but by the distance vertically from the suspending point to the plan in which the point of gravity of the weight swings. In figure 233 the line "CD" shows the length of the rotary pendulum. The rotation of this pendulum is equal to the double swing of a simple pendulum. It makes, therefore, only half as many rotations in a second as a simple pendulum of the same length will make; or, in other words, for one rotation a rotary pendulum requires twice the time that it takes a simple pendulum for a swing, when both are of equal length. The weight that rotates influences this pendulum as follows: the weight must correspond with the circle through which it travels; when the speed becomes greater than that for which the pendulum is constructed, the weight is influenced by the centrifugal force, and consequently it describes a larger circle; but when the weight is suspended, the distance vertically between its suspending point and the plan in which the point of gravity of the weight

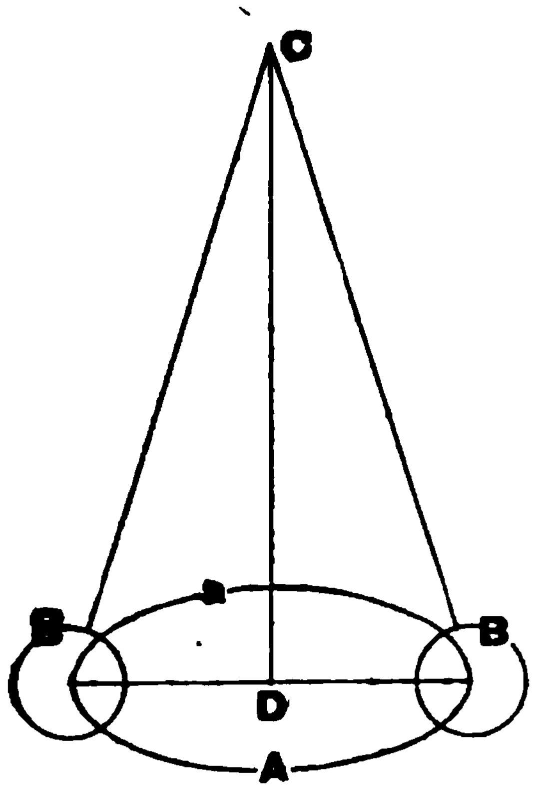


FIG. 233.

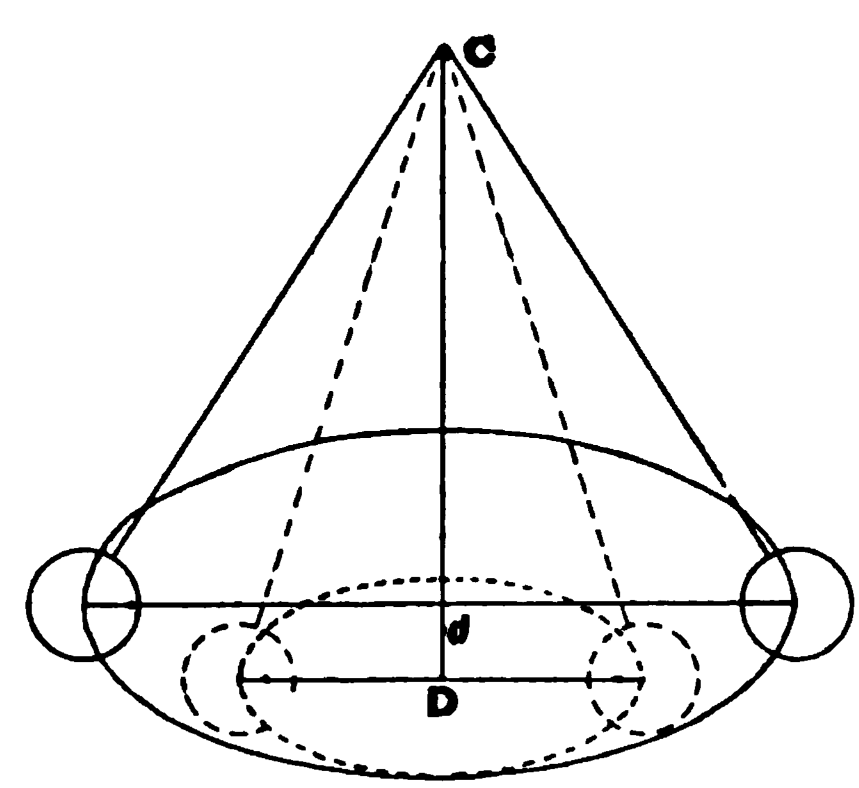


FIG. 234.

swings is diminished in size, corresponding with the speed of the pendulum. Figure 234 shows by the dotted lines the action of the pendulum as it acts when it makes the motion for which it is constructed, that is, according to its length; and the full lines show the difference when the pendulum is set in a greater speed. The vertical lines "CD" and "Cd" show the ratio in which the rotary pendulum was influenced. A rotary pendulum carries two weights; they are used to balance each other and keep the apparatus in a steady position; the two weights influence the pendulum as one weight would if equal to the two. See figure 234A.

Question 449—How is a rotary pendulum governor constructed?

Answer—Two balls act, in the pendulum governor, as weights, and are fastened on levers attached to a spindle that is brought in rotary motion by a pair of mitre wheels, one of which is fastened to the spindle, and the other to the governor shaft, which is brought in motion by pulleys, one of which is fastened to the crank-shaft of the engine, and the other to the governor shaft. Spindle and shaft work in the frame of the governor. The balls that here constitute the weight of the pendulum are at the same time acting as a lever. They act on one lever arm, while the other lever arm acts on a stem, which, when the speed of the rotary pendulum governor changes, is correspondingly either raised or lowered. Generally the stem is loaded with an extra lever on which acts a shifting weight. The Figure 235 shows a governor partly in section, in which 1 is a valve chamber, 4 is a frame, 5 are the mitre gears, 7 are the arms of the lever. 8 we call the toe plate, 9 the spindle, 10 the lever by means of which the spindle is loaded, 11 the fulcrum of this lever, 12 the step bearings acting against the spindle, 13 the pulley, 14 an oil cup, 16 the shaft bearings. 17 the stuffing box in which the stem slides, 18 is the head, 19 the arm-pins, 20 are arm-balls, 22 is the lever ball.

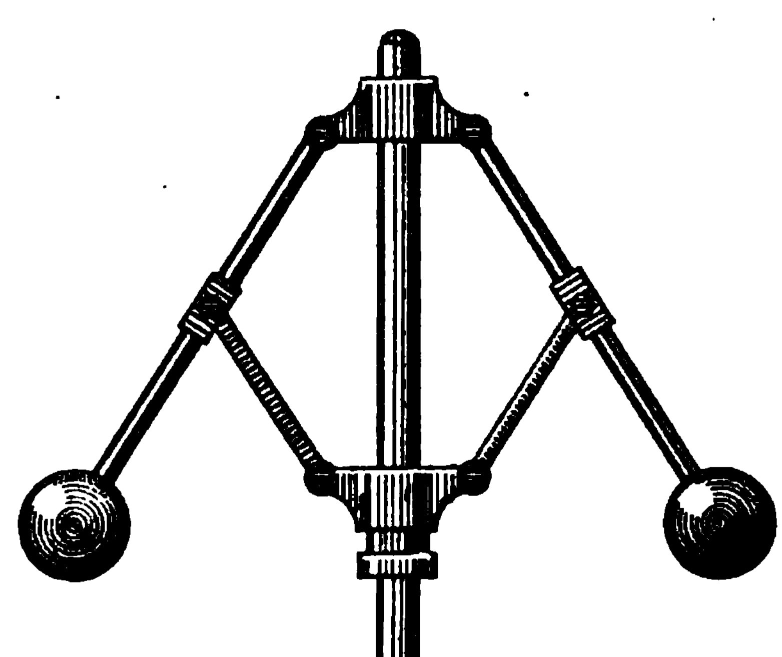


FIG. 234A.

Question 450—How does the pendulum governor act on an engine?

Answer—The pendulum governor acts either with its stem on a valve that operates in the passage of the steam from the boiler to the engine, leaving this passage free, if the engine has the speed for which the governor was constructed; and obstructing it if the engine has a greater speed than that for which the governor was constructed. Or the governor

can act with its stem by means of an extra mechanism so that the cut-off in the engine can be changed. With the first style the steam is throttled, consequently, expansion takes place in the passage of the steam without affording the advantage that otherwise had lain in the high pressure of the steam. Such an engine is called a common throttle-valve engine. In the second style the expansion takes

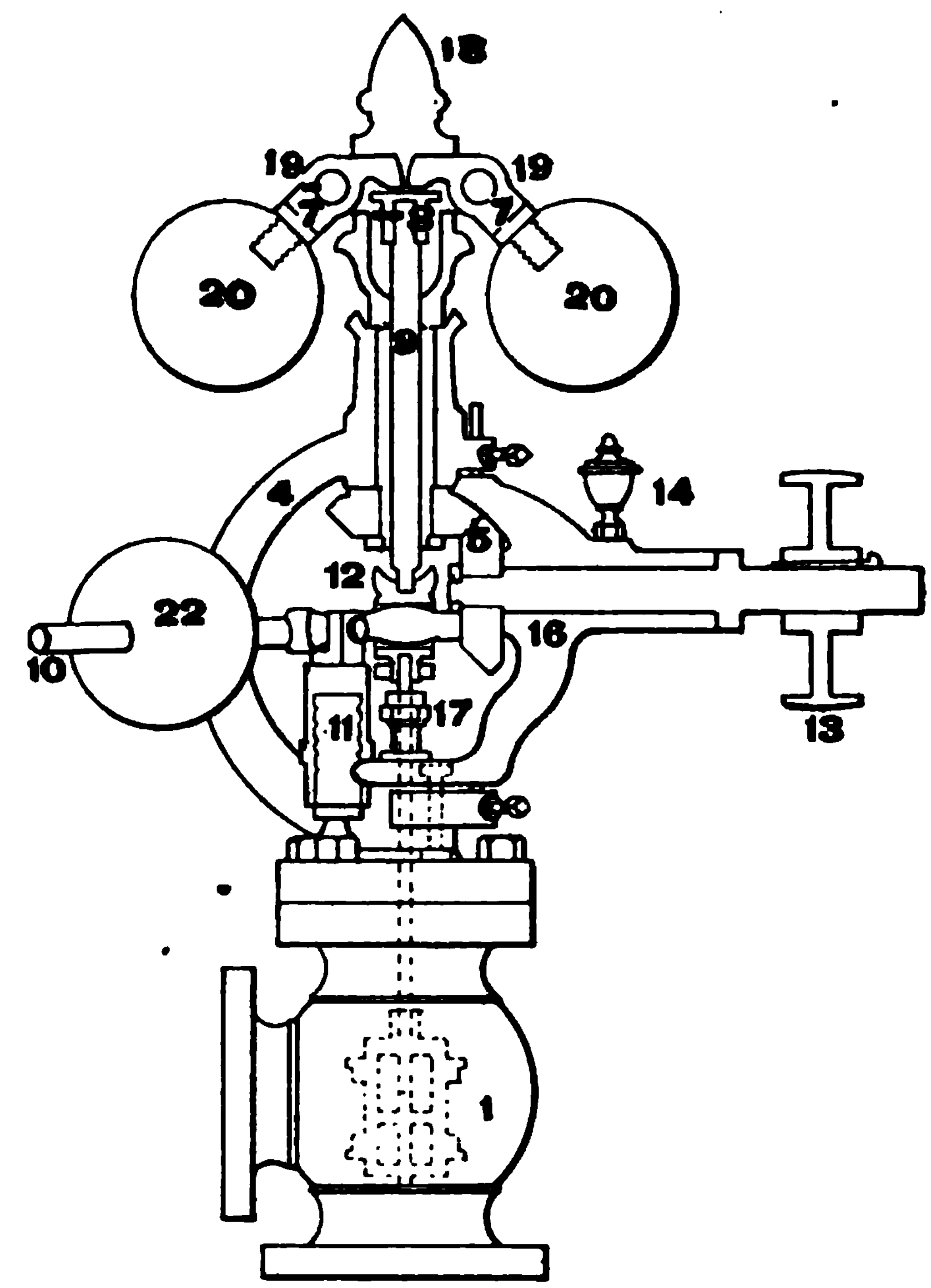


FIG. 235.

place only in the steam cylinder, giving us all the benefit of the power lying in steam that comes directly from the boiler without any obstruction. Such an engine is called, either an automatic engine, or an automatic cut-off engine.

Question 451—How is a shaft-governor constructed, and how does it act on an engine?

Answer—Springs that are loaded on one end by a weight, and fastened with the other end to the shaft directly, or to any other part that is attached to the shaft, have a tendency to bring their weights to a greater distance from the shaft, as soon as the speed of the engine forces, by centrifugal

power, these weights to swing around a larger circle. This motion of the weights is transferred to the springs, and if, from them it is transferred to an eccentric that slides in a stationary frame attached to the crank-shaft, the distance between the center and excenter of the eccentric will change, not only the throw, but also the extent to which the center of the eccentric had been placed out of plumb to the engine-crank; and the valve that stands under the control of such eccentric is enabled to change, automatically, the cut-off. This shaft governor can not act upon the passage of the steam from the boiler to the engine, but is bound to act only on the cut-off, consequently, it allows the expansion only in the steam cylinder.

FIG. 237.

FIG. 236.

FIG. 238.

Question 452—How should a rocker be arranged in order that by means of it the early cut-off of an engine may be adjustable?

Answer—If the swinging point of the rocker can be adjusted so that unequal length in the rocker arms results the traveling way of the valve is changed at the same time and, consequently, cut off. Figure 236 shows a rocker with arms of equal length, joined to a lap valve, the engine in dead line, and the lap extends over that port which is furthest from the piston, while the port nearest to the piston appears just ready to open. Figure 237 shows the same arrangement, but the top rocker arm is shorter than the lower one, here the lap appears shorter, and the port lying nearest to the piston is now just ready to open, for the valve extends over this too; this part of the valve is called its relap, while that part which extends over the port that is the furthest from the piston is now the acting lap, and while this is shorter than in the first arrangement the cut-off is a later one than that shown in Figure 236. Figure 238 shows the same arrangement, but the top rocker arm is longer than the lower one. In this figure the lap appears larger than in Figure 236, and the port that lies nearest to the piston stays open a little, while the lap is larger here, we see that we are able to make a still earlier cut-off than we could with the engine set as in Figure 236. The opening that appears at the port nearest to the piston we call the lead of the valve.

Question 453—What result does the relap of the valve produce in an engine?

Answer—A relap is a disadvantage to an engine in as far as the steam will be wire-drawn at the start of the stroke. The greater the relap, the greater the disadvantage.

Question 454—What result will a lead produce on an engine?

Answer—A lead is also a disadvantage to an engine in as far as it causes a counteraction against the piston. The steam has to enter before the piston completes its stroke, and, consequently, the engine has to complete its stroke with weakened steam against full pressure steam, requiring the use, and consequent loss, of a part of the power already accumulated in the fly-wheel. But the lead is advantageous in so far as it forms a cushion, taking up the lost motion which really can not be prevented entirely, especially in engines of a quick speed; otherwise the steam that is used to enter the stroke is not lost. It helps to start the stroke with full pressure steam, and assists the reverse of the stroke.

Question 455—Can you explain an engine that works with a variable cut-off?

Answer—We explained such an engine already by explaining the link motion used on an engine with early cut-off. In an engine arranged thus it lies in the will of the engineer to change the cut off at any moment.

Question 456—What are the names of the different types of valve gears which can be used on an engine?

Answer—1. The common slide valve gear. 2. The cam valve gear. 3. The drop valve gear (Corliss construction). 4. The oscillating cylinder valve gear.

Question 457—What definition can you give of the common oscillating cylinder valve gear.

Answer—We call a valve gear in which the valve is permanently in connection and motion with the contrivance that regulates its action a common slide valve, the contrivance used for the purpose must be either an eccentric or a valve-crank.

Question 458—What is the principle of a cam valve gear?

Answer—In the cam·valve gear the valve stands with the contrivance that must set it in motion, that is a cam, in permanent connection, but not constantly in motion. While the cam is continuously in motion, the valve comes in motion only momentarily if the early cut-off takes place, or if the stroke is reversed, otherwise it remains at rest. Only the cam is acting in this kind of valve gear as a contrivance. The cam, alone, acts as a contrivance in this kind of valve.

Question 459—What do you understand by a drop valve gear, and how does it act?

Answer—An engine provided with a drop valve gear has two steam valves and two exhaust valves. All four valves stand under control of one and the same contrivance, that is intended to regulate their motion. In this case the eccentric or valve-crank is used as a contrivance. The exhaust valves stand with the contrivance in permanent connection and permanent motion, but of the steam valves only one is brought in connection with the contrivance at the start of a stroke; it is able to remain in connection, or in motion with, the contrivance during the whole stroke, but it is discharged from it at the end thereof, and can be discharged before the stroke ends. Whenever the steam valve is disconnected from the contrivance it is bound to fall back to its seat, drop into it and so close the steam port. It can not be brought in connection with the contrivance again, either during the same stroke or during the next. The two steam valves so act with the contrivance alternating, during every pair of strokes.

Question 460—What is the difference between an automatic early cut-off engine and an automatic engine?

Answer—The valve gears of both types of engines stand under control of a governor, and are consequently both automatic cut-off engines, but that engine in which the common slide valve is used is called the automatic engine, and that in which the drop valve gear is used is called the automatic early cut-off engine. While in the automatic engine the valve keeps in motion after the early cut-off is made; in the automatic cut-off engine the valve is at rest during the time that the expansion takes place in the engine. Another difference is, that while the cut-off is limited in the automatic engine, it is unlimited in the automatic early cut-off engine. The automatic engine can stand under the control of a rotary pendulum governor as well as under the control of a shaft governor, while on the automatic early cut-off engine only a rotary pendulum governor can act.

Question 461—How do you describe an automatic engine standing under control of a shaft governor?

Answer—The principal part of such an engine is the shaft-governor. In Figure 239 a governor, in which a valve crank is used, the workings of the same may be clearly understood. A is the crank-pin, which is fastened to the arm B. This arm swings on a stud, C, which is fastened to one of the arms of the wheel near the hub, acting as a fulcrum. The weight D, which is at the longest end of the arm B, is the acting weight, and is held in position by a coil spring E, the weight resting against the stop F. It will be seen that the center of the crank-pin and the center of the shaft are at their greatest distance. In this position the governor will remain until the speed of engine increases a trifle beyond what it was constructed for, when the centrifugal power of the weight overcomes the tension of the coil spring and the center of crank-pin and the center of the shaft will come nearer together, and consequently shorten the throw and admit less steam to the cylinder. To prevent staggering, this governor is provided with a small cylinder with a perforated piston working in oil, which may pass to one or the other side of the piston gradually, thus keeping the governor steady. The weight G is simply a balance to weight D. In Figure 239A another type of shaft governor is illustrated, in which the eccentric is used, or rather two eccentrics; one is called the inner, marked C, and one we will call the outer eccentric, marked D, which slides upon the inner eccentric. The two crescent shaped weights, indicated by 1, are connected to the arms of the wheel in such a way that they may swing

towards the rim of the wheel, each in a different direction. The inner eccentric C, which slides on the shaft, is fastened to a yoke, indicated by dotted lines, and stands in connection with one of the weights 1, by means of the link rods, 2, at

FIG. 239.

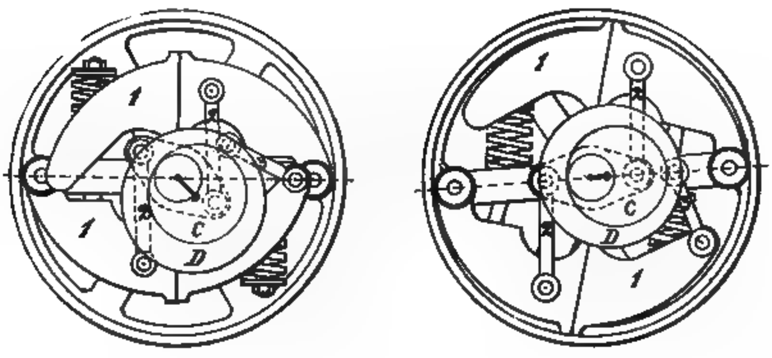


FIG. 239a. FIG. 239b.

each end. The outer eccentric D is connected to one of the weights only by link rod 3, and it will be readily seen must move in opposite direction of eccentric C. In Figure 239B the governor is shown in action. The weights 1 have changed their position, causing the inner eccentric to move in one direction while the outer one has moved in the opposite direction, bringing the center and excenter nearer together and making a shorter throw.

Question 462 How do you set the valve gear on an automatic engine that stands under the control of a shaft governor?

Answer—The crank-shaft should be pushed through the frame while the eccentric is resting in it. Then the center of the eccentric should be moved away from the center of the

shaft as far as the perforation in the eccentric allows. A piece of wood may be prepared to fill the space in the perforation of the eccentric, so that the center of the eccentric is steadied at its greatest distance from the center of the shaft. Then the distance between the center of the eccentric and the center of the shaft should be measured, and the width of a steam port subtracted therefrom. The remainder is half the lap, for which the center of the eccentric must be set out of plumb to the engine crank, in the direction the engine runs. When the eccentric is placed in this position the frame must be fastened to the shaft. The engine should then be placed in dead line, and the valve mounted on the chest-face, so that the full lap calculated extends over that port, which is furthest away from the piston. The valve rod should then be inserted now into the valve, linked to the eccentric rod, and the position of the valve on the valve rod secured by the gem-nuts.

Question 463—Is there only one or a number of constructions for an automatic engine that stands under the control of a rotary pendulum governor?

Answer—There are a number of constructions made for the purpose, of which Fink's and Meyer's are the most practical ones; the first is better known as the Porter-Allen construction.

FIG. 240.

FIG. 241.

Question 464—What is the principle of the Porter-Allen construction?

Answer—This construction is a combination of a part of the link-motion with an eccentric. Figure 240 shows a front view and Figure 241 side view, of this mechanism, known under the name "stationary link." A slightly curved arm, which is partly slotted, together with an eccentric strap, forms one piece. The crank lies with the great radius of the eccentric in one and the same line, and on both sides of this line a trunnion, by means of which the mechanism is linked to a stationary pin at the bed of the engine, to

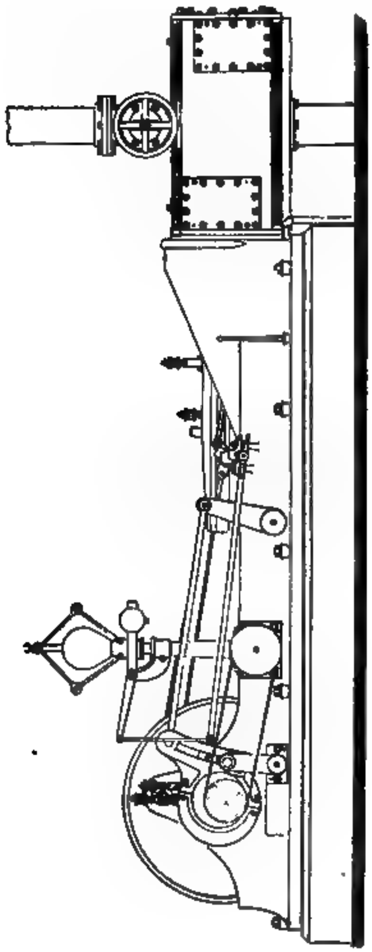


FIG. 242.

FIG. 243.

allow the trunnions to swing a distance equal to the throw of the eccentric, which represents only the length of the lap required, because the opening of the port is controlled by the slide block, which stands under the influence of the governor. This slide block travels up or down and so causes a longer or shorter cut-off. The motion is transferred to the steam valves by means of a rocker. The exhaust valves receive their motion from the same contrivance, although a separate rocker is used, which by means of a rocker shaft transfers the motion to the other side of the engine, as will be seen in Figure 242.

Question 465—How is Meyer's valve gear constructed, to act for variable or automatic cut-off?

Answer—In this construction three valves are used. A full pressure valve, and two others for expansion, which ride on the first. The two valves for expansion have a mutual valve-rod which is provided for each valve with a separate screw thread. Of these screw threads, the one is right handed and the other left handed. By a hand wheel "E," see Figure 243, the valve-rod can be turned around its own axis while the engine is running, consequently, in its length direction the motion of the valve-rod is free. This is arranged by means of a groove in the valve-rod, and a feather fastened to the hand-wheel, so as to act in the groove. By this the lap of the two expansion valves can at once be enlarged or diminished in size, and, consequently, the cut-off will thereby be changed. It is easily understood that, instead of the hand wheel, an arm is attached to the valve rod in the same way as the hand wheel, so that the governor, when acting by its stem on this arm, may operate this mechanism automatically.

Question 466—How are the valves constructed in an automatic early cut-off engine?

Answer—Either poppet valves or slide valves are used. The slide valves are formed either in cylindrical or conical shape. Figure 244 shows in a section the one end of a cylinder, in which "S" represents the steam valve, "E" the exhaust valve in cylindrical shape. The valves are arranged so that only the smallest amount of friction can take place, by cutting off as much from the cylinder shape as the figure shows. They are held tightly against their seats by slightly acting springs and by steam pressure. The ends of these valves extend out of a housing, and are provided on the outside with cranks.

Question 467—How are the valves moved in an automatic early cut-off engine?

Answer—Generally a wrist-plate is placed midway in the length of the cylinder. This is a plate provided with four wrist-pins

oscillating with the wrist-plate, by the motion which it receives from the contrivance, that acts on the valves. The cranks of the exhaust valves are moved directly by the wrist-plate, and therefore, directly connecting it by rods. But for the steam valves such a direct connection is not used.

Question 468—How are the admission valves engaged and disengaged in an automatic cut-off engine when under control of a governor?

Answer—In Figure 245 an illustration of the disengaging valve gear of the Frick & Co. pattern is given. A is the lifting arm, which is permanently connected to the wrist plate by means of the connecting rod B; to this arm A a latch or hook is attached, which is indicated in the drawing by C; the latch-die D, which is bolted to latch or hook C, is brought

FIG. 244. FIG. 245.

in contact with the stud-die E (indicated by dotted lines), which in turn is bolted to the team arm F. This arm is keyed to the valve stem, and is also called the valve crank. To secure a contact of the dies D and E, a spring is used, called the latch-spring, indicated by the letter G. The cam, or knock-off lever, H, which stands under the control of the governor, by means of the reach rod I, is provided with a cam, which is really called the knock-off cam, and is indicated by K. The latch or hook C, on one of its prongs is provided with a projection marked L, which, when coming in contact with knock-off cam K disengages the two dies

E and D, and consequently releases the steam arm or valve crank F from the lifting arm A and the valve is closed instantly through action of the dash-pot rod M. Now, it will be easily understood that the knock-off cam K, which is influenced by the governor, will alter its position and, therefore, will meet the projection L sooner or later and cause earlier or later cut-off. Figure 245A shows the valve gear, the rocker, and part of the governor. It will be seen that the four valves receive their motion from the wrist plate W, which in turn is connected to the rocker arm, R, by means of connecting rod C, which is also called the

FIG 245a.

carrier rod. This rod may be lifted from its wrist pin and the wrist plate may be worked by hand, to bring the crank wrist pin in the desired position for starting the engine. For such purpose a handle is inserted in the wrist plate, which is not shown in the drawing. The rocker arm R is provided with two wrist pins, one for the carrier rod and the lower one for the eccentric rod. The governor G is driven by a belt and gets its power from the crank shaft to the pulley marked P. The two exhaust valves E E are permanently connected to the wrist plate W, while the admission valves are constructed in the manner explained in Figure 245. DD are the dash-pots, r r the reach rods, which connect the governor with the admission valve AA.

Question 469—How is the valve gear set in a Corliss construction when poppet valves are used?

Answer—The eccentric or valve crank must be placed at right angles to the engine-crank, and fastened in this position; the engine is brought in dead line, and then the four ports are closed by the valves; as soon as the necessary connections are made the valve gear is set.

Question 470—How must the valve be set in an automatic early cut-off engine which works with slide valves?

Answer—The eccentric or valve crank must be placed at right angles to the engine-crank while the engine is in dead line, but it should not be fastened to the shaft. The four valves will be placed so that they just close the ports; then the necessary connections must be made. We then have to move the steam valve, which must begin to open first, so that it may receive a lap such as the size of the cylinder may require. By doing so we bring the great radius of the eccentric out of plumb, and in this position the eccentric or valve-crank must be fastened to the crank-shaft. The engine has to be reversed then, and if the lap on the other steam valve does not show the same size it was set at the first, we must correct by the set-nuts on the connecting rod to equalize. According to the size of the cylinder the lap will vary between 3/16 and 5/8 of an inch. Such a lap is a necessity in this kind of construction, because the least bit of leakage in the valve, which, by no means, can be prevented, would allow the passage of the live steam through the cylinder into the exhaust chest, while the engine is in dead line. The size of lap required on every engine is marked at the valve seat, or the wrist plate, respectively, which must be moved out of plumb to the extent required to give the lap, after it has been in plumb, while the valves just covered the ports.

Question 471—How many different types of expansion engines are in use and what are their names?

Answer—We have only an early cut-off engine and a compound engine as such.

Question 472—What is understood by the term "a compound engine?"

Answer—If we use in an engine two or more steam cylinders of different capacity, and let the steam, as it comes from the boiler, act first in the smaller cylinder and always exhaust or expand it in the next larger one, we call the engine a compound engine. By so expanding the steam we get the benefit of the expansion.

FIG. 246.

Question 473—Are there different kinds of compound engines, and if so, how do they differ from each other and what are their names?

Answer—We have two different kinds of compound engines. In the one kind the pistons of all the cylinders move during one stroke in one and the same direction; we call these engines by the number of steam cylinders used; thus: 2, 3 and 4 cylinder compound engines.

In the other kind of compound engines the pistons make alternate motions in the different cylinders, and the name of this kind of compound engine is derived from the number

FIG. 247.

of its cylinders, thus: twin, triple, and quadruple compound engines. The kind first mentioned is also called a cross compound engine. Of these cross compound engines there are two kinds. The axis of the cylinders lie either in one and the same plan, or they stand side by side. In the latter case we call the engine a beam compound engine. Figure 246 shows a two-cylinder cross compound, where the cylinders are lying in line. Figure 247 shows a two-cylinder beam compound, and Figure 248 a triple compound engine.

Question 474—What advantage has a compound engine over an early cut-off engine?

Answer—In an early cut-off engine the temperature of the cylinder varies from the beginning of the expansion to the end of the stroke, considerable. At every stroke, consequently, a good deal of steam is expended to reheat the steam cylin-

FIG. 248.

der and is, consequently, lost; while in a compound engine the difference of heat in the steam cylinders between the start of the stroke and the end of the stroke is very small.

Question 475—What do we understand by a condensing engine?

Answer—If the steam used in the engine does not exhaust into the atmosphere, but into an apparatus in which it is cooled off and becomes water, we reduce the counteraction in the engine; the apparatus in which this is accomplished is called a condenser, and the engine to which it is applied, a condensing engine.

Question 476—How far can the counteraction in an engine be reduced?

Answer—A perfect vacuum cannot result while the water from the condensed steam is at a temperature equal to the boiling point, and the warmer the water and the lower the pressure resting on it is, the easier an evaporation takes place. In the best constructed apparatusses there remains a pressure of $\frac{1}{8}$ of an atmosphere, and on an average we can call a condenser which reduces the pressure of the exhaust steam to two pounds per square inch a good one.

Question 477—What kind of condensers are used on engines?

Answer—There are two kinds of condensers; the one is called a surface condenser, and the other a jet condenser.

Question 478—How is a surface condenser constructed?

Answer—It is a casing divided in three compartments, the middle one of which has tubes running through it, which connect the two outer ones. The middle compartment is filled continuously with cool water, which is forced through the compartment, entering at the bottom and discharged at the top. It is constructed similar to a closed heater, but larger in size, and therefore offering a greater cooling surface to the steam. In the one outer compartment the steam, coming from the engine, enters, and in the other outer compartment the water that is a result of the condensation settles; from here the water is pumped into the boiler.

Question 479—What explanation may be given of a jet condenser?

Answer—The exhaust pipe is flattened at the end without obstructing the passage, so that it allows the steam to escape only in a long, but very thin, stream, and around this falls the cooling water. This kind of condenser is constructed in a great many varieties, but in all of them the water from the condensed steam is lost and, therefore, such a condenser is not economical, and is used only at such places as the application of the cooling water may be made without cost.

Question 480—What amount of cooling water is required for the condensation of steam?

Answer—Sixty-one cubic inches of cool water, in its passage through the condenser, absorbs from the steam only 25 units of heat, and inasmuch as 550 units of heat must be absorbed from the steam to condense it, 22 times as much water is used for the condensation of steam as resulting from it. The cold water pump of a condenser must, therefore, have 22 times the capacity of the warm water pump.

Question 481—How may we find the result produced by a condenser?

Answer—By a vacuum gauge.

Question 482—How is a vacuum gauge constructed?

Answer—It is constructed like the metal spring steam gauge, but it indicates the opposite of this; instead of right handed, left handed, while the metal pipe, when using live steam is expanding, and must act for this purpose by contraction.

Question 483—How do you read a vacuum gauge?

Answer—One atmospheric air pressure holds 29.9 inches mercury column in balance; the figure 30 does not vary much from this, and inasmuch as in common life 30 inches mercury column is adopted as 15 pounds pressure per square inch, the dial of a vacuum gauge is laid out according to it. The zero on the dial means that no pressure is taken from the atmosphere's pressure, and 30 means that the mercury column was reduced 30 inches, all the pressure is taken away; the vacuum results. And while each inch of the mercury column represents half a pound pressure, it means, when the vacuum gauge indicates one, that $\frac{1}{2}$ pound pressure is reduced from one atmosphere's pressure; when the vacuum gauge indicates twenty-six, that means that $26 \times \frac{1}{2} = 13$ pounds pressure is taken away from one atmosphere's pressure, and that consequently the remainder of $15 - 13 = 2$ pounds, are affecting the counteraction in the exhaust steam.

Question 484—If a four cylinder cross compound condensing engine has cylinders of the following dimensions: 6, 7½, 12 and 15 inches, the stroke is 18 inches, the over-pressure 85 pounds, and the number of revolutions 60 per minute, and the condensation reduced the counteraction to 2 pounds per square inch, how is the nominal horse-power calculated?

Answer—We have to consider, in this calculation, the real pressure, because we have to calculate the counteraction for each cylinder. We may take the atmospheric air pressure as 15 pounds, and so have $85+15=100$ pounds as real pressure per square inch. If we consider at the start, the cylinders as square boxes, then we would have the piston in the

first cylinder equal to 6x6 square inches. But in the second cylinder the steam reaches a larger room, and must expand there, and as the room increases the steam pressure will be diminished. We find, therefore, the steam pressure acting in the second cylinder by multiplying the acting real pressure by the area of the piston of the first cylinder, and dividing this product by the area of the piston of the second cylinder. That gives us this formula: $\frac{100 \times 6 \times 6 \times 2 \times 2}{15 \times 15} = 64$ pounds pressure acting against the piston in the second cylinder. The consequence of this is that there will be a counteraction in the first cylinder equal to that; therefore, in the first cylinder we have an over-pressure acting as $100 - 64 = 36$ pounds. In the second cylinder the counteraction is found in the same way. So we get the formula:

$$\frac{64 \times 15 \times 15}{2 \times 2 \times 12 \times 12} = 25 \text{ lbs. counteraction per square in.}$$

Therefore an over-pressure of $64 - 25 = 39$ pounds. The before mentioned counteraction, the 39 pounds, is acting now in the third cylinder; it is reduced as this formula shows: $\frac{25 \times 12 \times 12}{15 \times 15} = 16$ pounds counteraction. We get, therefore, in this third cylinder, $25 - 16 = 9$ pounds over-pressure. In the last, the fourth cylinder, where the 16 pounds counteraction of the third cylinder is acting, we have a counteraction of only two pounds, on account of the action of the condenser; therefore, an over-pressure of 14 pounds per square inch. In the first cylinder the action of the over-pressure is as $6 \times 6 \times 36 = 1296$ pounds. In the second cylinder as $\frac{15 \times 15 \times 39}{2 \times 2} = 2193\frac{3}{4}$ pounds. In the third cylinder as $12 \times 12 \times 9 = 1296$ lbs. In the fourth cylinder as $15 \times 15 \times 14 = 3150$ lbs. Now, if we add these four actions together, we get as total action in engine $1296 + 2193\frac{3}{4} + 1296 + 3150 = 7935\frac{3}{4}$ lbs. We may leave out the $\frac{3}{4}$ lbs. to simplify the calculation, and count only 79.35 lbs.; but these must be reduced because the piston is circular shaped, not square, consequently we must multiply the number by 11/14, and besides we took the whole total pressure, when we should have used only the twelfth part, therefore we must divide the product by 12. If we consider further the strokes

and their length and the number of revolutions, we get as formula

$$\frac{7935 \times 11 \times 2 \times 18 \times 60}{14 \times 12 \times 32500} = 3453 \text{ nominal horse power.}$$

Question 485—What profits will such a compound engine allow against a full pressure engine which uses the same steam?

Answer—If we refer to the engine mentioned in last question, we have to calculate the horse power which will result under full pressure in the first cylinder of the engine, if this is only used under the same conditions, that means under same pressure and with the same number of revolutions.

Question 486—What is a tandem engine?

Answer—When in an engine the power lying in steam is used out to its greatest possible extent and the steam is not necessarily used for reheating the steam cylinders at every stroke, we call the engine a tandem engine; that means that no more can be done to use the steam, the fuel, or the money in a more economical way. This is accomplished in automatic cut-off compound engines with condensation. The formula shows that such full pressure engine will have

$$\frac{6 \times 6 \times 11 \times 18 \times 2 \times 60 \times 85}{14 \times 12 \times 32500} = 13.32 \text{ nominal horse power.}$$

While from the compound condensing engine mentioned in last question, we obtained as a result 34.53 nominal horsepower, which proves, that to run this compound condensing engine is $34.53 \div 13.32 = 2.6$ times as cheap as to use the same steam in a full pressure engine.

Question 487—What is the difference between a twin engine and a twin compound engine?

Answer—In the twin engine each cylinder receives its steam from the boiler, while in the twin compound engine, only the first cylinder receives steam from the boiler and exhausts it into the next one.

Question 488—What kind of valve gears may be used on a compound engine?

Answer—On a compound engine may be used all three valve gears: the common slide valve, the cam valve, and the drop valve gear.

Question 489—How is the valve gear arranged on a cross compound engine?

Answer—On a cross compound engine we have only one crank to the shaft, no matter how many cylinders are used. But we use for each cylinder a valve, but the valves have to be

put in motion altogether by only a single contrivance, fastened to the crank-shaft. An extra contrivance may be fastened to the crank-shaft when in the first cylinder an early cut-off must be made, then upon the first cylinder an extra expansion valve with its contrivance is required. An expansion valve may quite as well be set to each cylinder as a D lap valve and one extra contrivance only, operating these expansion valves must be set on the crank-shaft, but this will suffice for all the expansion valves; but only when no earlier cut-off than three-quarter is desired, one contrivance operates all expansion valves.

Question 490—How is the valve gear arranged upon a twin, triple or quadruple compound engine?

Answer—In this kind of compound engine a crank is required for each cylinder. In consequence of this, not only a valve for each cylinder is necessary but, also, a contrivance to set this valve in motion. An early cut-off can take place in the cylinder or a number of them quite as well, but for each expansion valve an expansion and an eccentric is needed, when a three-quarter cut-off will not satisfy.

Question 491—Can a link motion be used in a cross compound engine?

Answer—Yes, but it must be used either as a full pressure construction or an expansion construction, and a double eccentric is necessary as a contrivance to set the valves in motion as described for the link motion.

Question 492—Can the link motion be used in a twin, triple or a quadruple compound engine?

Answer—We require, when the link motion is used, for every valve, a double eccentric as described for the link motion; the rockers which bring the stone in due position, are on a mutual shaft, and one set lever with nutched segment operates the cut-off, or reverse of stroke.

Question 493—How is the valve constructed which admits steam to the steam cylinder of a simplex steam pump?

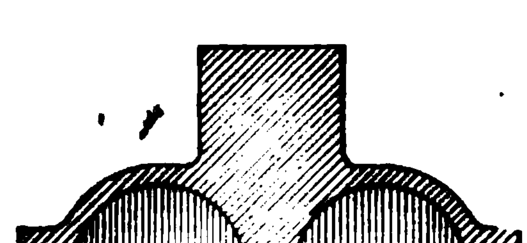


FIG. 249.

Answer—Such a valve has two exhaust cavities as Figure 249 shows. Each exhaust cavity is in length three times the

width of a steam port, and the face of the valve shows three plans, each one of the width of a steam port. The whole length of the valve is, consequently, nine times the width of a steam port.

Question 494—How is the steam cylinder constructed for a simplex steam pump?

Answer—The steam cylinder of a simplex steam pump shows on its chest-face three ports of equal width. The middle one is the exhaust port leading to the exhaust pipe, while the two outer ones are steam ports. The chest face is raised above the steam cylinder equal in height to once the width of a

FIG. 250.

FIG. 251.

steam port, and so four bridges are formed, each of which is equal to the width of a port. The whole chest-face is consequently, equal in length to seven times the width of a steam port. The area of a steam port is equal to 1/25 of the area of the bore of the steam cylinder, the width of a steam port is 1/5 of its length, and the distance between the two steam cylinder heads will be generally equal to 12 times the width of a steam port plus the width of the steam piston.

The channels through which the steam must pass, enter the bore of the cylinder, either at the cylinder heads, or at a distance therefrom of 2½ times the width of a steam port. Figure 250 shows the position of the steam channels as first mentioned, and Figure 251 where they enter the bore at a distance from the cylinder head.

Question 495—How is the valve which admits and discharges steam to and from the cylinder of a simplex steam pump, set in motion?

Answer—The valve which admits steam to the cylinder, and discharges the exhaust steam from a simplex steam pump, must be set in motion by an auxiliary valve, which is called the chest-piston or the piston valve. It receives the steam, by which it is set in motion, either directly or indirectly from the steam chest, and we call that valve which admits steam to, and discharges it from the steam cylinder, the main valve.

Question 496—What do we mean when we say that the piston valve receives steam either directly or indirectly from the steam chest?

Answer—Whenever the chest-piston is made to receive the steam by a peculiar twisting motion, it receives the steam directly from the steam chest and if an extra valve or valves that are commonly called auxiliary valves, are necessary to admit the steam from the steam chest to the chest-piston, then we have an indirect admission of the steam to the chest-piston. When the steam is acting on the one side of the chest-piston to set it in motion, the steam from the other side must exhaust, and this steam is discharged in both cases through extra channels, directly into the exhaust pipe.

Question 497—How many different types of valve gears for simplex steam pumps are in use?

Answer—We use three different types: 1. The motion of the steam cylinder piston sets the auxiliary valves in motion, which admit and discharge steam to and from the chest valve, so that by its motion, the main valve can be set for the reverse of the stroke. 2. The motion of the piston rod can be transferred to a valve rod, which is attached to the chest-piston, in such a form that the chest valve swings around its axis, and so that the steam is directly admitted to the chest-piston; and while the valve rod is not hindered by its twisting motion from making a length motion, the steam placed behind the one end of the chest-piston, sets it in motion and, consequently, brings the main valve into the position that it can reverse the stroke of the cylinder steam piston In this construction the steam which had been standing on the other

end of the chest-piston, will be discharged through auxiliary channels, directly into the exhaust pipe. 3. The motion of the piston rod is transferred to a valve rod, which sets in motion an auxiliary valve that admits and discharges steam to and from the chest-piston by auxiliary channels, so that it is bound to move, enabling by its motion the main valve to govern the reverse of the stroke of the steam cylinder piston.

Question 498—Why can not the main valve be set in motion by a valve rod, that receives its motion through the piston rod, for the purpose of reversing the stroke of the simplex steam pump?

Answer—In a steam pump we have neither a crank to arrest, nor a fly wheel to reverse the stroke of the steam piston as in an engine or engine pump. In the steam pump the speed of the piston increases, that is it gets faster and faster the nearer the piston comes to the end of the stroke. Consequently, when the piston rod would by means of a valve rod transfer the motion directly, to the main valve, a contact stroke of the main steam piston could not be prevented because steam, as a counteraction, cannot be admitted sufficiently to the steam cylinder before the piston completes its stroke. Therefore, to avoid a contact stroke, steam must be admitted to the cylinder before the piston completes its stroke, in fact it must be done so that the chest-piston may begin to move, and take the main valve along while the cylinder steam piston stands at a distance of 2½ times the width of the steam port from the cylinder head, when the steam cylinder is of ordinary length, that is with the distance between the steam cylinder heads equaling 12 times the width of a steam port, plus the width of the piston. But when the steam cylinder is made extraordinary longer, the motion of the main steam valve must begin earlier, because on account of the greater length of the stroke, the speed of the steam piston must increase, and steam must enter the steam cylinder earlier, to absorb this speed, as a counter action, before a contact stroke can take place.

Question 499—What kind of simplex steam pump can you describe, relative to the different types of valve gears in use?

Answer—There is such a variety of simplex steam pumps that only a few examples may be given of the different types of valve gears. For instance, we will first mention a type in which the whole valve gear lies inside of the steam cylinder, by reason of which it is called a direct acting simplex steam pump. In this connection we refer the reader to one kind of Hookers pumps, and to the Cameron pump. For the second

type where the valve rod is attached to the chest-piston, reference to the Knowles steam pump is sufficient. For the third type, where the valve gear is constituted by transferring the motion of the piston rod to a valve rod which is attached to an auxiliary valve, the Deane pump, another Hooker pump construction as already mentioned, the constructions of Blake, and of Dean Bros., may be referred to.

Question 500—Can the whole motion of the piston rod be transferred to a valve rod?

Answer—We have already stated that the motion of the main valve should start when the piston stands at a distance of 2½ times the width of a steam port from the cylinder head or earlier; here is mentioned the steam port that lies in the chest face of a steam cylinder, on which the main valve is acting. Therefore, the motion that the steam cylinder piston makes before it arrives at this respective point of the cylinder, must be a dead motion in regard to the valve rod, and, consequently, this part of the stroke is called the slack of the pump.

Question 501—How large must the slack be in a pump?

Answer—The slack in a pump must be equal to the contact stroke of the piston minus five times the width of a steam port, of the size that lies on the chest-face of the steam cylinder, provided the steam cylinder is of the ordinary length, otherwise more must be subtracted from the contact stroke.

Question 502—How do you measure the contact stroke?

Answer—The contact stroke is found by subtracting from the distance between the two cylinder heads, the width of the steam piston. The length of the contact stroke can easiest be measured at the piston rod, by moving the steam piston once to the outer steam cylinder head and once to inner steam cylinder head, and making in each position a mark at the gland of the steam cylinder stuffing box on the piston rod; the distance between these two marks is the length asked for.

Question 503—How large must the traveling way of a valve be in a steam pump?

Answer—It must be equal in length to twice the width of the port which lies in the face in which it is traveling.

Question 504—How can the motion of the piston rod of a simplex steam pump be transferred to the valve rod, when an auxiliary valve is attached thereto?

Answer—The motion of the valve rod may be transferred in a simplex steam pump to a valve rod which is attached to an

auxiliary valve, either by means of a tapit or a rocker. While the piston rod is making its motion, the tapit is sliding free on the valve rod during the slack; then it strikes one of the set collars, which sets the valve rod with the valve in motion. Between the two set collars lies the slack and the width of the tapit. If a rocker is used, the dead motion between the set collars which are fastened on the valve rod, must be equal to the contact stroke, as it is reduced by the rocker, minus five times the width of that steam port the valve is operating on; but this is also subject to the length of the steam cylinder.

Question 505—How can the motion of the piston rod of a simplex steam pump be transferred to the valve rod, when a chest piston is attached thereto?

Answer—To transfer the motion of the piston rod to the valve rod, a chest valve is attached to a tapit, a rocker, a ball joint, and an adjustable connecting rod between the ball joint and rocker is used. The tapit which is fastened to the piston rod, carries in itself a roller that is adjustable in height. While the tapit moves with the piston rod, the roller must keep a free passage, equal to the length of the slack required, between the arms of the curved rocker which lies in a horizontal position. As soon as the roller touches one arm of this rocker, it raises it and the motion thus begun is transferred through a twisting motion to the chest valve by means of the ball joint that is fastened to the valve rod and is connected to the rocker by the adjustable connecting rod. The amount of this twisting motion can be regulated by a set nut, used to lengthen or shorten the connecting rod between the ball joint and the rocker.

Question 506—What must be done first, if you intend to set the valve gear on a simplex steam pump, in which the motion of the piston rod is transferred to a valve rod to which an auxiliary valve is attached?

Answer—First we must ascertain that the slack is transferred to the valve rod in the proper form, by marking the due position of the set collars on the valve rod. For that purpose we have to bring the steam piston to the middle of its stroke, and the auxiliary valve to the middle of its seat. Then we have to fasten the tapit, if such is used, in the middle of the piston rod; or when a rocker is used, we place it on its support, hanging plumb to the piston rod, and arrange it in this position to the piston rod, so that it may be guided by this. Then we place the collars in equal distances to tapit or rocker, so that half the slack lies on either side of them, and mark this position as due to the slack.

Question 507—How do we ascertain that the steam piston of a pump stands in the middle of its stroke?

Answer—We loosen the gland as well as the follower on the steam and water cylinder, then make a contact stroke with the steam piston at the outer steam cylinder head, and while the piston is standing in this position, make a mark on the piston rod at the steam cylinder stuffing box. Then we make a contact stroke with the steam piston at the inner steam cylinder head, and also make a mark on the piston rod at the steam cylinder stuffing box. Then we make another mark midway between these two marks. If we push the piston so far that this middle mark stands at the steam cylinder stuffing box, we have the steam piston in the middle of its stroke.

Question 508—How can we locate the middle of the piston rod?

Answer—We first make a contact stroke with the steam piston at the inner steam cylinder head, and make a mark on the piston rod at the water cylinder stuffing box. Then we make a contact stroke with the steam piston at the outer steam cylinder head, and make a mark on the piston rod at the steam cylinder stuffing box. Midway between these two marks will be found the middle of the piston rod.

Question 509—When a steam pump has been taken to pieces and must be set up for use again, how do you proceed with it?

Answer—We must commence on the water side of the steam pump, and, therefore place the water piston on the piston rod, push the free end of the piston rod through the water cylinder and its stuffing box, and then slide the follower and gland for the water cylinder stuffing box over the piston rod; then, likewise the gland and the follower of the steam cylinder stuffing box, and push the water piston into the water cylinder, and then the piston rod into the steam cylinder stuffing box. Make then, with the water piston a contact stroke with the inner water cylinder head, and fasten the steam cylinder on the piston rod. Push the steam piston back into the steam cylinder, and close the outer heads of water and steam cylinders. Insert the receiving valves of the pump, then the discharge valves, and mount on top of the air chamber by placing the required gaskets between the single parts which must fit water tight. After this is done, we may proceed to set the valve gear.

Question 510—How must the valve gear be set for a simplex steam pump, in which the auxiliary valve is set in motion by a valve rod, receiving its motion from the piston rod by a tapit?

Answer—The main valve as well as the chest-piston must be placed in the middle of their seat, when piston is in the middle of its stroke. Therefore, the chest-piston must be placed in the middle of the length of its bore, and the main valve must rest on the middle of the length of steam cylinder chest face. The valve rod must be inserted into the steam chest and pushed through the opening leading to the valve rod stuffing box; then the valve rod stuffing box with follower and gland, and also the set collars and the guide of the valve rod must be slipped over the valve rod, and fastened in due position. The steam chest with the chest valve inserted therein, and the auxiliary valve slipped over its rod must then be placed on the steam cylinder and fastened thereto by using a gasket to tighten it thereon. If then the heads on the steam chest are tightened and the stuffing boxes provided with the necessary packings, the steam pump is ready to receive them.

Question 511—How must the valve gear be set when the motion of the piston rod is transferred by a rocker to the valve rod which regulates the auxiliary valve?

Answer—After the steam piston is set in the middle of the stroke, the rocker placed in plumb and joined to the piston rod so that it can be guided, and the valve rod, with collars in due position, attached to the auxiliary valve lying in the chest, with the main valve and chest valve placed in the middle of their seats, the steam chest will be mounted on the steam cylinder and by means of a gasket, connected with it steam-tight. From the description of the single pumps other items will be recollected.

Question 512—How must the valve gear be set for a simplex steam pump, when the motion of the piston rod is transferred to the valve rod of the chest piston?

Answer—First it must be ascertained how large the twisting motion of the chest valve must be. Therefore, the position of the channel which lies nearest to the outer head of the chest valve must be marked on this head, and the position of the steam port and exhaust port in the chest bore must also be marked at the outer flange of the steam chest, because the mark that is on the outer head of the chest valve must be brought in connection with the steam port once and in connection with the exhaust port in the steam chest bore once. After this is done, the piston must be placed in the middle of its stroke, and the tapit fastened on the piston rod so that its middle line will stand opposite to the swinging point of the rocker, which must be placed in horizontal position, and

the roller in the tapit should be adjusted to allow a free passage between the rocker arms to the extent of the slack required. After placing the main valve and chest piston in the middle of their seats, and fastening the steam chest to the steam cylinder by using a gasket as packing, we slip over the valve rod the inner chest head, the follower and the gland of the valve rod stuffing box, then the ball joint, the top part of the tapit, the set collar and the valve rod support; then hook the valve rod into the chest piston by letting the top part of the tapit slip into the socket of its lower part, and fasten the inner chest head to the chest and the valve rod support to the water cylinder. Then fasten the ball joint and the set collar at a distance from each other equal to the lower end of the curved rocker, so that the inner sides of these will stand in plumb with the end point of the lower side of the rocker. Then, by means of the adjustable connecting rod, we join the ball joint to that rocker arm which lies nearest to the steam cylinder, and when sufficient swing is not afforded each stroke at the back flange of the steam chest, we adjust the connecting rod by means of the set nut until this effect takes place. The outer chest head should then be fastened to the chest, and when the necesary packings are placed in the stuffing boxes, the steam pump is ready to receive steam.

Question 513—How must the valve gear be set in a steam pump with inside valve movement?

Answer—In this kind of steam pump the valve gear is set when the main valve is guided by the chest valve; all that has to be done is place main valve and chest valve in the middle of their seats and then fasten the steam chest steam tight to the steam cylinder. Auxiliary valve or valves must be set automatically by the steam piston or by the pressure of the steam.

Question 514—Why are the auxiliary ports not as wide and besides, in area, smaller than the main port leading to the steam cylinder of a simplex steam pump?

Answer—There are two reasons for this:—First, the bore of the cylinder is considerably larger than the chest bore; second, while the area of the port leading to the steam cylinder must be one-twenty-fifth of the orea of its bore, the area of the port leading to the chest-piston need be only one-fiftieth of the area of the chest bore.

Question 515—How does the steam act in the steam cylinder of a steam pump?

Answer—When the steam moves the piston its speed is accelerated and must be retarded, in a steam pump, when the piston is at a distance of two and one-half times the width of a

steam port from a cylinder head. Then begins the motion of the valves, and while the main valve travels through the width of one steam port, the steam admitted is gradually wire-drawn and the exhaust steam gradually cramped. But as soon as the motion of the main valve equals once the width of a steam port the admission of steam as well as the exhaust thereof is stopped. When, through the motion of the engine, the valve starts to travel further, the steam enters in front of the piston, while from behind the piston the previous driving steam exhausts; consequently this action begins when the piston stands at a distance of one and one-half times its width from the cylinder head. There is no longer any driving power behind the piston, but instead a counteraction by steam in front absorbs the speed of the piston before a contact stroke takes place, and thus steam pressure is on hand to reverse the stroke.

Question 516—How does the steam act against the chest valve in the chest-bore of a simplex steam pump?

Answer—The admission of steam to the chest valve must be so calculated that it cannot make a larger traveling way than is due to the main valve; therefore, the admission of steam thereto must take place through a steam port smaller in width and area, so that the steam that enters the bore already wire-drawn can act on the chest valve in its consistancy only through a short distance, while at the same time the exhaust is free on the other side of the chest valve; but then the steam admitted expands and the exhaust steam cannot escape, and is therefore compressed during the end of the traveling way of the chest piston, the stroke of which is consequently stopped in due time.

Question 517—Can't you transfer the whole motion of the piston rod of a simplex steam pump to a valve rod carrying an auxiliary valve without a slack?

Answer—The dead motion can be substituted by attaching to the auxiliary valve a lap equal to the slack. This lap will prevent the entry of steam into the bore during exactly the same part of the motion as was attended by the slack.

Question 518—How should a simplex steam pump be started?

Answer—When a simplex steam pump is stopped so that the piston stands at a greater or less distance from a cylinder head than one and one-half times the width of a steam port, every construction of the pump will start as soon as steam is turned on, but, otherwise, the chest-piston or the main piston must first be moved by a starting lever.

Question 519—How can steam reverse the stroke in a simplex steam pump when the steam channels enter the bore of the cylinder at a distance of two and one-half times the width of a steam port where the piston is bound to cover the ports, and consequently no steam can enter the cylinder to cause the reverse motion of the piston?

Answer—Those steam cylinders in which the main channels enter the bore at a distance of two and one-half times the width of a main steam port from the cylinder head have auxiliary channels through which steam can enter in front of the cylinder at the same moment that the main channels should admit steam. These channels are formed either as grooves in the bore of the steam cylinder; or they form an extension of the main steam channel communicating with the end of the cylinder; or from the steam chest they communicate with the end of the steam cylinder; in either case they are covered by a lap that may be on the auxiliary valve or on the main valve during the time that the valve is at rest.

Question 520—How should the steam cylinder be constructed for a duplex pump?

Answer—The chest face of the steam cylinder in this variety of pumps shows five ports. The middle one, twice as wide as the four others, acts as the exhaust port, and therefore leads to the exhaust pipe. Between the ports are bridges equal in size to once the width of a steam port. The channels through which these four other ports communicate with the bore of the cylinder connects therewith as follows:—The two outer ports reach the bore at the end of the cylinder, that is at the cylinder heads, while the two ports that lie next to the exhaust port reach the bore of the cylinder at a distance of two and one-half times the width of a steam port from the cylinder heads, so that between each two ports the bridge is of the width of one and one-half times that of a steam port.

Question 521—How is the valve constructed that is used in the steam cylinder of a duplex pump?

Answer—The valve is equal in length to ten times the width of a steam port, with an exhaust cavity midway thereof equal

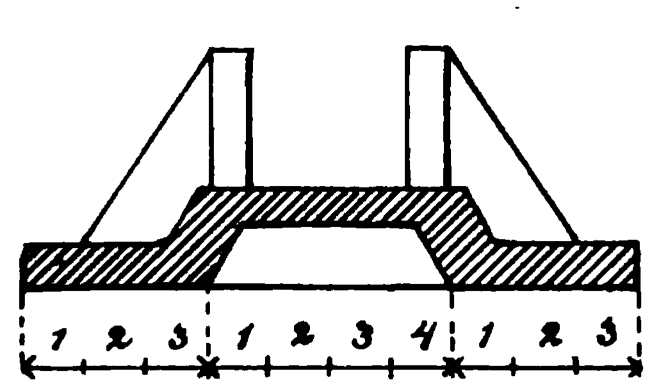


FIG. 252.

in length to four times the width of a steam port. Consequently it is of sufficient capacity to cover all five ports, as figure 252 shows.

Question 522—How can the motion of the piston rod in a duplex steam pump be transferred to the steam valves?

Answer—Two rocker shafts are placed on supports and the large rocker arm of one shaft is guided by the piston rod of one cylinder, while the small rocker arm of the same shaft is operating the valve of the other steam cylinder; the other rocker shaft acts vice versa.

FIG. 253.

FIG. 254.

Question 523—Is there a slack to be considered in the construction of a duplex steam pump?

Answer—We must consider the same slack in a duplex pump as in a simplex pump; that is, the slack is equal to the contact stroke, minus the width of five steam ports. It is transferred by the rocker arms to the valve rod on which set collars may act either directly against the valve or against a stationary projection on the chest; in the latter case the valve is fastened to the valve rod.

Question 524—How must the valve gear be set on a duplex steam pump?

Answer—The two steam pistons should be placed in the middle of their strokes, and the rocker arms set plumb to the piston rod with the large rocker arms attached to the piston rods so as to be guided thereby. Then the steam valves must be mounted on their respective seats, so as to cover both outer ports in the chest face. Then the valve rods must be inserted and joined to the respective short rocker arms, and the set collars adjusted to the valves so that the slack may be equally divided. Then one of the large rocker arms must be placed out of plumb until the outer port of the opposite steam cylinder is quite open. Then the valve gear is set. The figure 253 shows the duplex pump when the rocker arms are in plumb; figure 254 when valve gear is set; in neither of the figures are the chests shown, and valves appear in section.

Question 525—How does the steam act in a duplex steam pump?

Answer—The steam must enter the cylinders before the stroke is completed, because the steam accelerates the speed of the piston in the duplex pump quite as much as in the simplex pump. When the steam piston arrives at a distance of three and one-half times the width of a steam port from the cylinder head, it begins to close the channel that lies nearest to the exhaust port, cramps the exhaust, and when it arrives at a distance equal to two and one-half times the width of a steam port from the cylinder head, the steam cannot exhaust at all. The exhaust steam is now compressed while the driving steam is becoming wire-drawn, which continues till the piston arrives at a distance of one and one-half times the width of a steam port from the cylinder head. At this moment the steam begins to enter in front of the piston, and the driving steam begins to exhaust. When the steam piston has arrived at a distance of two and one-half times the width of a steam port from the cylinder head toward which it is moving, the slack is used up on the valve of the other steam cylinder, which is then ready to start.

Question 526—Are the alternate strokes in a duplex steam pump always equal and regular?

Answer—The strokes are equal and regular only when both double acting pumps are in perfect good order, and when no hindrance results from packing either too tight or too loose.

Question 527—Can a simplex steam pump be constructed so that an expansion can take place in its steam cylinder?

Answer—We cannot construct a simplex pump acting under expansion neither with early cut off nor with compound cylinders.

Question 528—Can a duplex pump be constructed so that expansion can take place therein?

Answer—A duplex pump cannot be constructed for early cut off, but it can be constructed with compound cylinders, and so act under expansion.

Question 529—How should the valve gear be set in a compound duplex pump?

Answer—A compound duplex pump must be constructed so that it is cross compound, with the axis of the cylinders lying in one and the same line. The pistons must be set in the middle of their strokes, and the rockers with their arms placed in plumb to the piston rod and arranged there so that the piston rods can guide the large rocker arms; the valves on all steam cylinders must just close their respective ports, and when the valve rods are inserted and joined to the short rocker arms the slack must be arranged so that it may be equally divided, lying either to both sides of the valve, or of the projection, or of the set collar, as may be required.

Question 530—How do you start a duplex pump?

Answer—A duplex pump is always ready to start; all that is necessary is to turn the steam on, because a steam port must be open either in one or the other steam cylinder.

Question 531—In what ratio must the steam cylinder stand to the water cylinder in a steam pump that must receive steam from the same boiler that it feeds with water, in regard to diameter and areas?

Answer—In a steam pump we lose more of the power invested than in an engine pump. While in an engine we count upon a loss of forty-two and one-half per cent., in a steam pump we are bound to count on a fifty per cent loss of power. This shows evidently that the area of the steam cylinder must be twice as large as that of the water cylinder, and if we place the diameters of the steam cylinder and the water cylinder in ratio as five to three and one-half, then we get the steam cylinder a little larger in area than twice that of the

water cylinder. This ratio must be adopted in the construction of steam pumps, and will fill the required conditions.

Question 532—Are steam pumps useless in which the before mentioned ratio varies, and in which, consequently, the area of the steam cylinder may be more than twice as large as that of the water cylinder, or when the water cylinder is larger than the steam cylinder?

Answer—Such steam pumps can be used, but only for lifting water into tanks, or for feeding boilers, with steam coming from another boiler.

Question 533—If we should feed a boiler that stands under sixty pounds pressure with a steam pump in which the water cylinder is of the same size as the steam cylinder, and use the steam from another boiler, how high can the pressure be in that boiler only?

Answer—Inasmuch as we lose fifty per cent of the power in the steam cylinder, the pressure in the boiler from which we take the steam must be twice as large as the pressure in the boiler that we must feed.

Question 534—If we have a boiler that carries one hundred pounds steam pressure and bring it in connection with a pump, the steam cylinder of which is eight inches in diameter and the water cylinder thereof six inches in diameter, and we shall feed another boiler therewith, under what pressure can that boiler stand?

Answer—The pressure exerted against the piston of the steam cylinder is $100\times8\times8\times11/14$, we lose half of this power, consequently the net result that acts against the water cylinder is only half the pressure that acts against the steam piston; and if we now divide this half by the area of the water piston, we know what pressure acts against each square inch of it. This is, consequently, equal to the boiler pressure against which we must feed. We receive the formula:

$$\frac{100\times8\times8\times11\times \qquad 14}{14\times2\times6\times6\times11}=88\ 8/9 \text{ pounds.}$$

Question 535—If we have a steam pump connected with a boiler that carries one hundred pounds steam pressure, and the steam cylinder of this pump is six inches in diameter, and the water cylinder eight inches, how high can it lift water?

Answer The pressure that is effected by the steam against the steam piston is equal to $100\times6\times6\times11/14$. We lose half of this effect, and if we divide the remaining half effect by the area of the water piston, which is $8\times8\times11/14$, we know what effect is acting on every square inch of the water

piston. If we divide the number of pounds which we have to the square inch now by 14 7/10, and multiply the quotient by 33,885, we have the height to which water can be lifted by this pump expressed in feet; so we get the formula:

$$\frac{100\times6\times6\times11\times \qquad 14\times33.885}{14\times2\times8\times8\times11\times14.7}=64.83 \text{ feet.}$$

Question 536—How can we calculate the capacity of a steam pump?

Answer—We cannot count the stroke as it is given by the dealers in their catalogues, as there the contact stroke is mentioned; by no means should we consider more than eleven-twelfths of that stroke. Besides this, we must recollect that the pump delivers only seven-eighths of that amount of water for which it was constructed for.

Question 537—How many gallons of water will a steam pump deliver by each stroke if the contact stroke in the steam cylinder is twelve inches, and the diameter of the water cylinder is ten inches?

Answer—We multiply the area of the water cylinder, which is 10×10×11/14, by the contact stroke, which is 12, and of this we count only 11/12. Then we will have, in cubic inches, the amount of water that could be delivered by the pump if it were in perfect good order, but of this we can count only seven-eighths, bearing in mind that the pump is kept only in average good order. If we then divide the number of cubic inches of water that can be delivered by every stroke by 232, the number of cubic inches contained in a gallon, we answer the question. We receive the formula:

$$\frac{10\times10\times11\times12\times11\times7}{14\times \qquad 12\times8\times231}=3,274 \text{ gallons.}$$

Question 538—Are water and steam cylinders of equal length in steam pumps?

Answer—The water cylinder is necessarily longer than the steam cylinder, otherwise the water piston would close the water passage between the pump chamber and the valves.

Question 539—What advantage do we gain by the inequality in the length of water and steam cylinders in steam pumps?

Answer—The inequality in the length of water and steam cylinders in steam pumps facilitates the introduction of the water and steam pistons to their respective cylinders. Thus we are enabled to mount the water piston direct on the piston rod, and push the piston rod with the water piston through the

stuffing boxes and into the water cylinder. Then we take the contract stroke with the water piston at the inner water cylinder head, the piston rod extends so far out of the steam cylinder that we can place the steam piston on piston rod with ease.

Question 540—How is the piston rod of a steam pump measured?

Answer—If we take the distance between the vertical middle line at the receiving and discharge opening of the water cylinder and a line extending through the exhaust pipe opening, and add to this distance the width of the steam piston, and

FIG. 255.

allow sufficient for fastening the water and steam piston, we have the exact length of the piston rod for a steam pump.

Question 541—In what direction must the simplex pump be started?

Answer—Quite immaterial is the direction in which the piston must go when the pump is started.

Question 542—How is the Knowles pump constructed?

Answer—The figure 255 shows a vertical section of the steam end and valve gear of the Knowles pump. In this the principal parts are indicated as follows:

1. Steam cylinder.
2. Steam piston.
3. Piston rod.
4. Tapit.
5. Tapit tip.
6. Rocker bar.
7. Connecting rod.
8. Ball joint.
9. Valve rod collar.
10. Valve rod support.
11. Steam chest.
12. Supplemental piston.
13. Valve rod.
14. Main valve.
15. Steam inlet.
16. Exhaust.
17. Cylinder head for water cylinder.

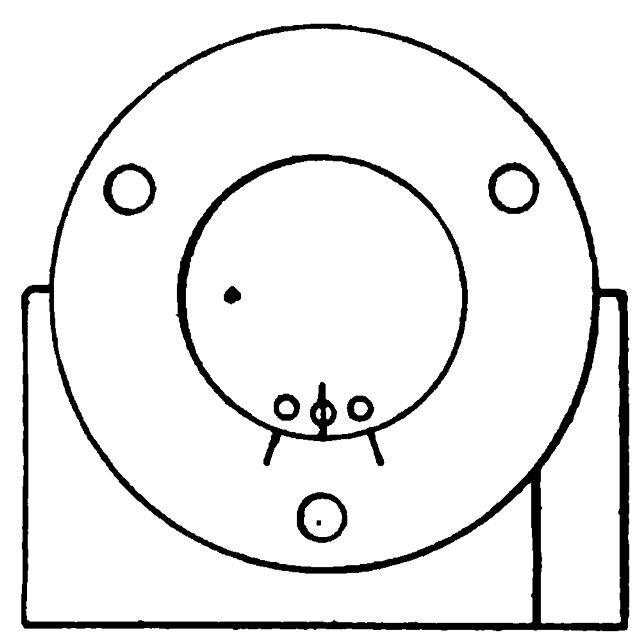


FIG. 256.

The Knowles pump is the type in which the motion of the piston rod must be transferred to a valve rod fastened to the chest piston for the purpose of giving to the chest valve a twisting motion. The valve gear in this pump must be set as follows:— The outer head of the chest piston must be marked so that the position of the steam channel that lies on the face of the chest valve nearest to its end may be located there. In the same way marks must be made on the outer chest face showing the location of the steam and exhaust ports in the bore of the chest. Figure 256 shows outer chest piston head and outer chest flange with these marks. When the piston is set in the middle of its stroke, then we fasten the tapit on the piston rod, so that its middle line stands opposite to the center of the pin that sustains a support in the middle of the rocker. The roller should be inserted in this part of the tapit below the rocker and the main valve placed in the middle of its seat, the chest valve in the same way, and the steam chest should then be placed on the steam cylinder and fastened there steam tight

after the valve rod is slipped into the inner head of the chest valve; but before we slip it in, we first slip over it the inner chest head, then the follower and gland of the steam chest stuffing box, then the ball joint, the tapit tip, the set collar, and the valve rod support. By inserting the valve rod into the chest valve we must let the tapit tip slip into the socket of the tapit arm. The inner chest head should then be fastened to the chest, and the valve rod support to the water cylinder. When the rocker is set and leveled we fasten to the valve rod the ball joint and the set collar, each with its inner side in plumb to the lower corners of the rocker, and fasten the tapit tip to the tapit; then connect the rocker arm that stands nearest to the steam cylinder to the ball joint by means of the adjustable connecting rod. The roller must then be adjusted in the slot of the tapit, so that it will keep free passage between the rocker arms. Then we must set the piston in motion, and in case the right swing is not given to the chest valve by every stroke, we must correct the length of the connecting rod with the set nut until we get the right swing of the chest valve as it was marked. When the outer chest head is fastened to the chest and the stuffing boxes are provided with a sufficient packing, the pump is ready to receive steam. To understand the action of the steam in the pump, we must examine the following illustrations:—Figure 257 shows a top view of the chest face of the steam cylinder of the Knowles steam pump. Figure 258 shows a side view, and figure 259 the bottom view of the main valve. Figure 260 shows a side view, and figure 261 a bottom view of the chest valve. Figure 262 shows a view of the inner chest valve head. In figure 257 we see at the middle of the view

FIG. 257.

two steam ports with the exhaust port lying midway between them. On the one side of these ports, the width of which is shown, are two extra ports close by, which are indicated in the figure by "A" and "B," while "C" and "D" are the main steam ports, and "E" the exhaust port. The two ports "A" and "B" are ports for auxiliary channels, each of which respectively connects the steam room in the chest with one end of the cylinder. These auxiliary channels are a necessity, otherwise steam could not enter in front of the steam piston when it covers the main channel. One of these ports is opened at the moment that the main steam port lying nearest to the piston receives steam. These auxiliary ports are closed by the two laps "F" and "G" on the main valve. These laps

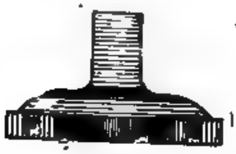


FIG. 258. FIG. 259.

FIG. 260.

FIG. 261.

FIG. 262.

are exhibited in the figures 258 and 259. They cover the auxiliary ports at the moment the main ports are closed, and one of the auxiliary ports opens at the same moment that the main port lying nearest thereto receives steam. These auxiliary channels pass through the mantle of the steam cylinder. On the chest face of the steam cylinder is another port, indicated by "H" in the Fgure 257. This port would be closed by the steam chest mantle, were it not split in twain by an auxiliary channel extending through the mantle of the steam chest and connecting it (port "H") with the bore of the steam chest at each end thereof. These auxiliary channels act as exhaust channels. The hole "H" communicates directly with the exhaust pipe, while the exhaust ports in the bore, which are indicated by dotted lines in figure 255, and marked there with "I" and "K," lie at greater distance from the heads of the chest valve than the steam ports "L" and "M;" shown in the same figure, the steam channels leading to the chest bore and directly communicating with the steam room in the chest. When the valve gear is set, as demonstrated in figure 255, the pump cannot receive steam unless it is started by moving either the steam piston or the chest piston. The tapit tip slides on the valve rod, and should not touch either the set collar or valve clamp, although a very little space must remain between them and it. Only if the chest valve sets tightly the tapit tip must strike the set collar or valve clamp. The two exhaust cavities that are indicated in figures 255 and 259 by "N" and "O" act reciprocally, the one for the steam inlet and the other for an exhaust at each stroke. When the piston arrives at a distance of two and one-half times the width of a steam port, at that moment a twisting motion of the chest valve takes place, caused by the roller, which raises one of the rocker arms. At the moment that the twisting motion takes place, and while the steam piston is still moving, the chest valve receives steam behind that head which is furthest from the steam piston, and therefore moves at once in the opposite direction, changing the position of the main valve in the chest, and likewise the action of the cavities in the same, and at the same time opening the auxiliary channels and turning steam in front of the piston, which acts as a cushion to absorb the speed of the piston which then stands ready to reverse its stroke. At the moment that the chest valve receives steam on one side by reason of the twisting motion, the channels in it nearest the steam piston are brought in contact with the exhaust port, thus permitting the steam that would otherwise hinder the motion of the chest valve to exhaust, thereby allowing the chest

valve to move as far as the traveling way of the main valve requires. When the chest valve begins to move it moves in the same direction that the steam piston moved before it completed its stroke.

Question 543—How is the Dean (Holyoke, Mass.) steam pump constructed?

Answer—This is a pump that is constructed on the principle of transferring the piston rod motion to a valve rod that acts on an auxiliary valve. Figure 263 shows a sectional view of it. Figure 264 shows a top view of the cylinder chest face. Figure 265 is a top view of the auxiliary valve. Figure 266 is a bottom view of the same. Figure 267 shows a side view of the auxiliary valve, with a part of the valve rod. Figure 268 is a side view, 269 a end view, and 270 a bottom view of the main valve. Figure 271 shows a sectional view of the chest valve, figure 272 a bottom view of the same, and figure 273 a side view of the chest valve. The principal parts are marked with the following figures in these illustrations:—

FIG. 263.

1. Is the steam cylinder.
2. Is the water cylinder.
3. Is the steam piston.
4. Is the chest piston.
5. Shows a tapit arm complete.
6. Is the main steam valve.
7. The auxiliary valve.
8. The air chamber.
9. The piston rod.
10. Is the valve rod.
11. Is the water piston.

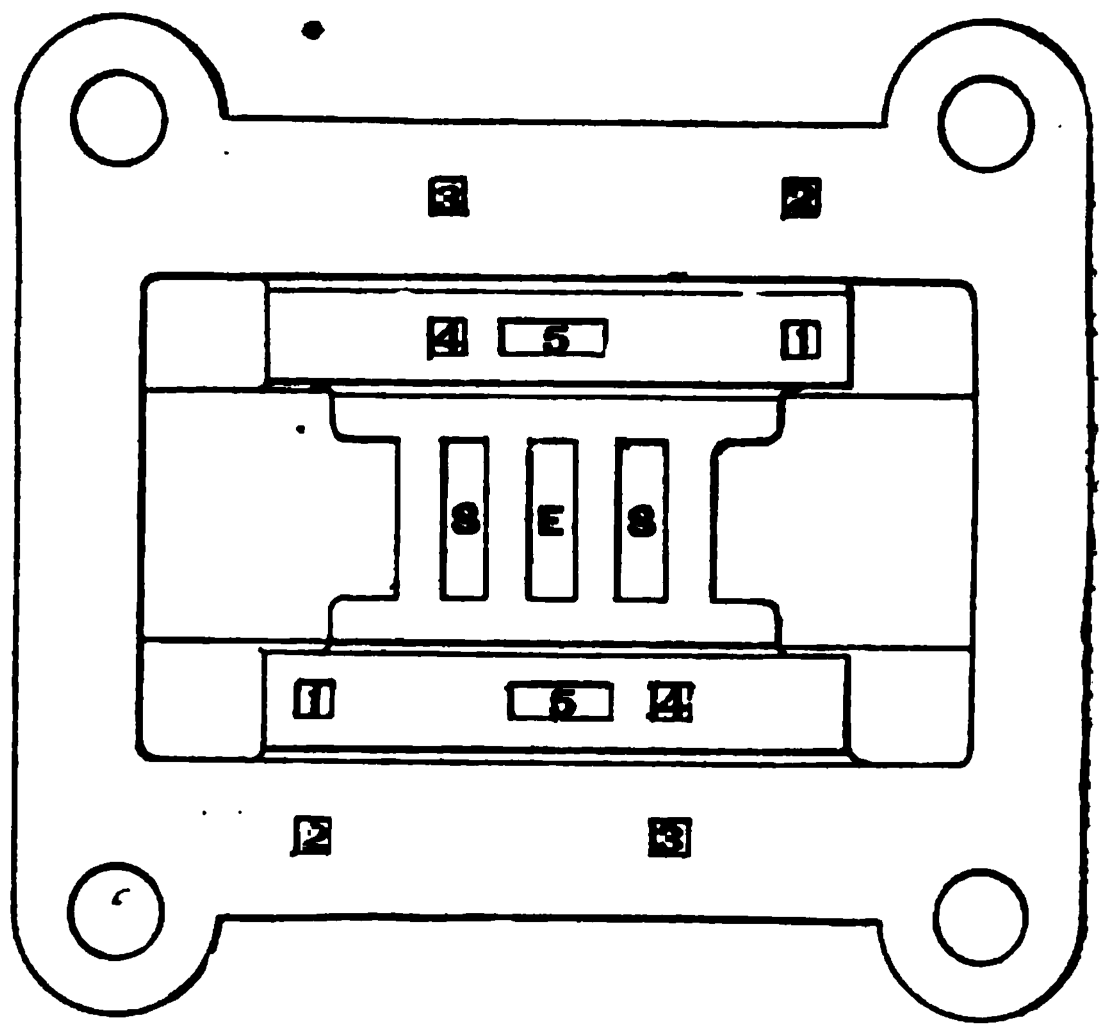


FIG. 264.

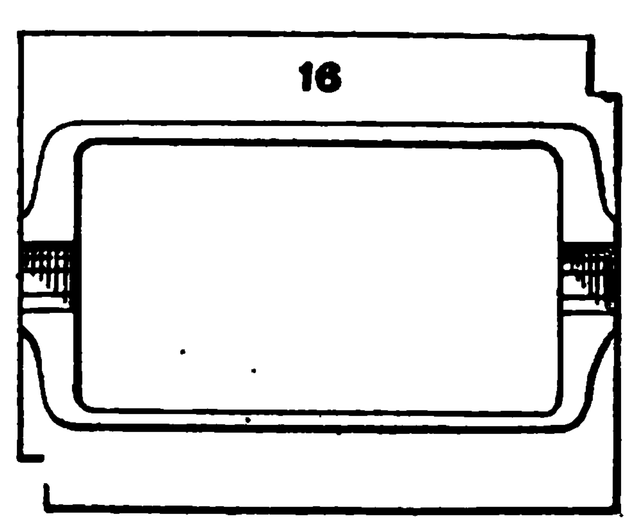


FIG. 265.

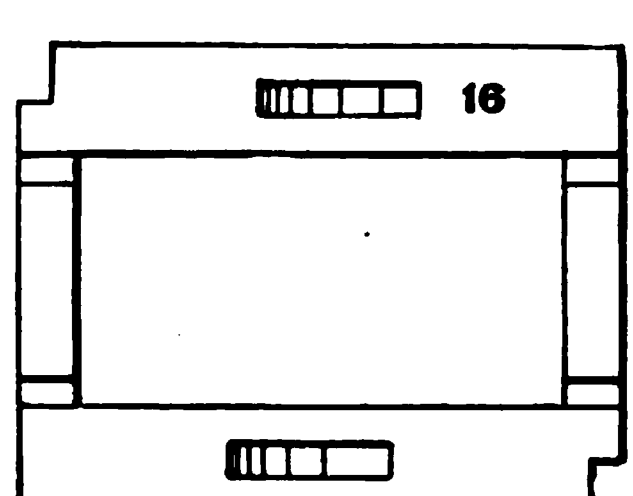


FIG. 266.

The main valve in this construction is surrounded by a frame-shaped auxiliary valve that acts independently and is fastened to a valve rod by means of a yoke that slips over the auxiliary valve, and which rod has a free passage in the middle of the main valve. In the cylinder chest face there are, in addition to the three ports on which the main valve oper-

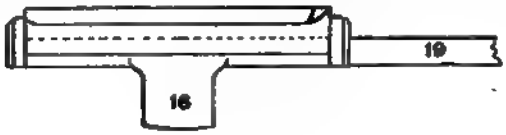


FIG. 267.

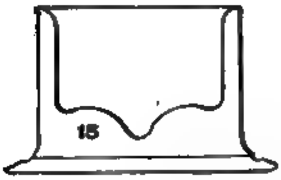


FIG. 268.

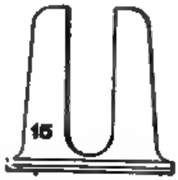


FIG. 269.

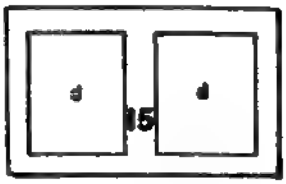
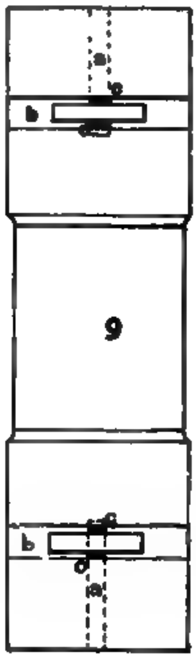


FIG. 270.



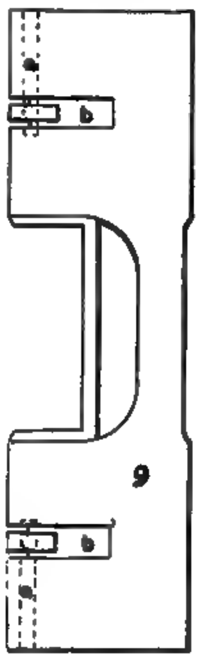


FIG. 271. FIG. 272. FIG. 273.

ates, ten other ports. Six of these are covered by the auxiliary valve, and the other four are covered by the mantle of the steam chest. In the bottom of each length side of the auxiliary valve is a cavity that facilitates the exhaust out of chest bore. In Figure 264E is the exhaust port of the main valve, SS are steam ports for same, 3, 4 and 5 are auxiliary exhaust ports, 1 and 2 are auxiliary steam ports. The auxiliary steam ports as well as the auxiliary exhaust ports communicate with the bore of the chest. The six ports that are indicated by 1, 4 and 5 on both sides of the main ports are covered by the auxiliary valve. As soon as the auxiliary valve is forced, by the piston rod, to move, after the tapit has passed through the slack, one of the auxiliary ports indicated by 1 is opened. Steam is admitted to the chest valve (supplemental piston) through port 1 which communicates by means of a small channel under the valve-face, with port 2 then passing through the mantel of the steam chest into a port indicated by A in figure 271 which leads to the end of the supplemental piston and the chest-head. The piston with the main valve is now forced the required distance ahead to open the opposite main steam port. At the same time exhaust cavity of the auxiliary valve which is shown in figure 266, is placed over the exhaust ports 4 and 5, the latter communicating directly with the main exhaust pipe. The steam on the other end of the supplemental piston exhausts through the ports 3, 4 and 5 similar to that of the admission of the steam. The return stroke is accomplished the same way, only the ports on the other side of the main ports being in action, steam being admitted and exhausted alternately, first on one and by the return stroke on the other side. Inasmuch as in this construction the main steam channels strike the bore in a distance of 2½ times the width of a main steam port from the end of the cylinder, an auxiliary channel must conduct steam to each end of the steam cylinder; consequently these auxiliary channels connect the main steam channels directly with the ends of the steam cylinder; they are indicated in Figure 263 by the letter H. Before composing the valve gear for this pump we must distinguish the due position of the set collars on the valve rod. For that purpose we place the piston of the steam cylinder in the middle of its stroke, fasten the tapit in the middle of the connecting rod, place the auxiliary valve in the middle of its seat. Then slip the two set collars and the valve rod guide over the valve rod, and the valve rod, with its yoke, and mount it on the auxiliary valve, by letting its guide slip into its socket at the water cylinder, leaving on each

side of the tapit one set collar, and placing the valve rod into the chest of the tapit; then mark the position of the set collars, as they are adjusted to each side of the tapit at a distance equal to half the slack. Then we must take auxiliary valve and valve rod off the steam cylinder, and take them apart again. When the steam piston is in the middle of its stroke, we place the main valve in the middle of its seat. In the same way we arrange the chest valve in the middle of the bore, then from the inner side of the steam chest push the valve rod towards its outer side, and slip the inner chest head on the valve rod; then the stuffing box with the follower and gland, and likewise the two set collars and the valve rod guide. Fasten the set collars on the valve rod in due position and insert the auxiliary valve into the yoke of the valve rod. When the inner cylinder head is fastened to the chest it must be reversed, that is, set upside down on the cylinder, and connected with the steam cylinder steam tight. When the outer chest head is fastened to the chest and the stuffing boxes are supplied with packings, the steam pump, together with its valve gear, is completed. In case that the chest valve does not commence its motion in due time, the lug not shown will strike the main valve and start the motion of the chest piston. As soon as the steam piston is brought near the end of its stroke, the pump is started.

Question 544—How is the Blake pump constructed?

Answer—In this pump the main steam channels strike the bore of the steam cylinder at its ends; and an auxiliary valve stands under the control of a valve rod, to which the motion of the piston rod is transferred by a rocker. Figure 274 represents the Blake pump in sectional view. Figure 275 shows the top view of the cylinder chest face. Figure 276 is a top view of the auxiliary valve with a part of the valve rod inserted. Figure 277 is a top view of the steam cylinder, showing the chest in section. Figure 278 is a side view of the auxiliary valve, and Figure 279 is a perspective view of the auxiliary valve. In this pump the main valve appears as a D valve, because it has only one cavity, but while the main valve is moving with the auxiliary valve in the opposite direction, it is acting with the auxiliary valve together, as a B valve. In the before-mentioned figures, A means the steam cylinder with the steam piston; H and H1 the two main steam channels leading to the ends of the cylinder; M is the discharge to the exhaust pipe. The auxiliary valve is marked with C. This has three passages, two for steam inlet, E and E1, and in the middle the exhaust

passage K. The piston rod which moves this auxiliary valve is marked P. D. is the main valve and B the chest valve. The auxiliary valve is provided with three laps. Two laps are laying on one side of it and are marked as S and S1. They are acting on auxiliary ports N and N1, which are openings for steam channels, which are bringing the steam from the main chest to the bore of the chest for the

FIG. 274.

FIG. 275.

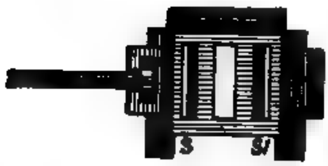


FIG. 276.

FIG. 277.

FIG 278.

FIG. 279.

purpose of setting the chest valve in motion. When chest valve, main valve, and auxiliary valve are standing in the middle of their seats, the openings N and N1 are closed by these laps, but one of them will be opened at once, as soon as the slack is used up, and set collars, which are fastened to the valve rod, are bound to move the auxiliary valve. On the other side of that auxiliary valve is another lap V, where two cavities, which are marked R and R1, are placed. The one of these cavities is discharging steam at the one end, the other at the opposite end of the chest bore. X and X1 are the ports through which this exhaust steam must pass through these cavities into Z, the port which leads to the exhaust pipe. These cavities, during the one stroke opening X, during the other stroke opening XI, will be brought in communication with the port Z. Auxiliary channels are passing through the mantle and marked in the Figure also as X and X1 on the one side as exhaust from the chest bore, and as N and N1 on the other side of the steam chest as steam admittance to the chest bore. The steam enters the chest at S and exhausts at T. The Figure 280, shows the Blake pump complete in side elevation. A is the steam cylinder and W the water cylinder. The valve rod is marked as Px. On the valve rod we see a guide which is fastened to the water cylinder and marked with 1. The two set collars on the valve rod are marked with 2. Between these two set collars is a contrivance sliding, which is called a sliding tapit, and is mentioned in the drawing as 3. This sliding tapit is linked to the rocker 4 by the link 5, to the short rocker arm at 6. The long rocker arm is guided at 7 by the piston rod A1. The motion of the piston rod will be so transferred to the auxiliary valve. The valve rod P is provided with a head 8, which is able to pass through the opening in the steam chest, if the stuffing box 9 is taken out of the chest. When the valve gear for the Blake pump shall be set, the position of the set collars on the valve rod has to be ascertained first. To do this the auxiliary valve will be placed in the middle of its seat while the piston rod is standing in the middle of its stroke, and the rocker is standing plumb to the piston rod, and arranged to it so that it can be guided by the piston rod. After we placed the head of the valve rod into the recess of the auxiliary valve we slip over the valve rod one set collar, then the sliding tapit, and then the other set collar and the valve rod support, which will be fastened now to the water cylinder. The next will be to link the sliding tapit to the lower rocker arm and place then the two set collars in such a distance from

the sliding tapit that each distance is equal to half the slack. This position of the set collars has to be marked on the valve rod. Before we can compose the valve gear now, we have to unlink the sliding tapit from the rocker, then take off the valve rod support from the water cylinder head, and displace the valve and valve rod by separating the pieces. We place, while the piston rod is in the middle of its stroke and rocker guided by the piston rod, the chest valve in the middle of its seat, insert the main valve in the recess of the chest valve and push through the chest hole, out of which the stuffing box is taken, the head of the valve rod,

and place the auxiliary valve on top of the main valve, so that the head of the valve rod reaches into the recess of the auxiliary valve; cover then the chest by a small piece of iron sheet, reverse the chest and place it on the steam cylinder and fasten it thereto steam tight. Then we slip over the valve rod the stuffing box, the follower and gland, the one set collar, the sliding tapit, the other set collar and the guide, and fasten the latter to water cylinder and the two set collars in due position to the valve rod. After we insert the stuffing box of valve rod in chest, we fasten the heads to the chest and pack the stuffing boxes.

Question 545—How is the Hooker steam pump, with outside valve gear movement, constructed?

Answer—This steam pump has the main steam channels lying in a distance of 2 1/2 times the width of a main steam port from the cylinder heads. Figure 281 shows the steam cyl-

FIG. 281.

inder with the outside valve gear movement, and the letters and figures placed in the illustration indicate the following articles: 1 is the main steam cylinder, 2 is the main steam piston, 3 is the valve chamber, 4 the main steam valve, 5 is the piston rod, 6 is the chest valve, 7 is the auxiliary valve, 8 is the auxiliary valve rod, 9 is the stuffing box for same, 10 is a hand movement for main valve, 11 shows the piston

rod gland, with follower inserted; 12 is the guiding piece of the rocker, 13 is the long rocker arm, 14 is the rocker shaft, 15 represents the valve arm, free swinging on the rocker shaft; 16 is the short rocker arm, which is tight fastened to the rocker shaft, like the long rocker arm; the latter is allowed to slide lengthwise; the short rocker arm has the name, dog plate. 17 are the dogs which give the former plate the name and they are representing the set collars. 18 is the wrist-pin fastened to the valve arm 15, making out of this a blind-crank. In the Figure 282, is shown a cross section in the middle of the steam cylinder. Figure 283 is a top view of the steam cylinder chest face without chest. We see in these figures the steam inlet pipe at the cylinder, mentioned with 19, and the exhaust pipe at the cylinder with 20; a, a1 are the main steam ports; b, b1 are auxiliary steam ports, the channels of which are leading the steam to the steam cylinder in front of the steam piston; c is the main exhaust port; e, e1 are auxiliary ports, the channels of which are leading to the chest bore; and f is the auxiliary exhaust port which carries the steam by its channel from the bore to the exhaust pipe; g and g1 are cushion valves, an extra arrangement which is shown only in the Hooker construction at the chest valve.

FIG. 283.

FIG. 282.

FIG. 284.

FIG. 285.

FIG. 286.

FIG. 287.

FIG. 288.

FIG. 289.

FIG. 290.

Figure 284 shows us a top view of the main valve. Figure 285 shows a top view of the auxiliary valve. Figure 286 shows a sectional view of main valve, and Figure 287 a sectional view of auxiliary valve. Figure 288 shows a sectional view of chest piston, with cushion valves and a part of the steam chest. The main valve is a D valve, while the auxiliary valve is made after the B pattern in this construction. The chest piston is slotted out as shown in Figure 289, so that it can be set in motion by the hand movement marked 10. Figure 290 shows a bottom view of the chest piston. These two last named figures will serve to illustrate this explanation. The auxiliary valve admits and discharges steam to and from the chest bore, as mentioned already, through ports and channels e, e1. The cushion valves g will cover the auxiliary channel on that side of the chest piston where steam shall enter. The cushion valve will be raised in its bore, so that the steam is really able to enter the bore between chest valve and chest head through the channel which is opened by this rising, but as soon as the chest valve made a part of its motion the steam pressure which is laying between chest valve and chest head is pressing this auxiliary valve down again, on account of the channel f in chest valve, and so when the chest valve has made its motion it does not allow all the exhaust steam to leave the bore, the exhaust steam which remains is bound to be compressed and forms a cushion. The setting of the valve gear of the Hooker steam pump with outside valve movement must be done as follows: The cushion valves will be inserted in their recesses at the chest piston. The chest piston is then placed in the middle of its seat, and when main valve is placed in the middle of its seat the chest will be placed on the steam cylinder steam-tight thereto after the auxiliary valve is set. To do this, we first place the piston in the middle of its seat, fasten the great rocker arm to the rocker shaft, set it in plumb to the piston rod, and arrange it so that it is guided by the same. We place now the auxiliary valve in the middle of its seat, insert through the stuffing box the valve rod, and adjust it to the valve by a nut, which is laying in the recess of the auxiliary valve, so that the valve arm, which is oscillating free on the rocker shaft, stands in plumb when the wrist-pin of this valve arm is connected to the rod of the auxiliary valve. The dog plate will be then fastened to the rocker shaft so that each dog stays in equal distance to the valve arm. The chest will be closed now, by its heads, the stuffing boxes will be supplied with the necessary packings, and by the hand

movement marked 10 the main valve will be set so that steam is able to enter the cylinder. The description, as the manufacturer has given it, for this steam pump is as follows: "The parts being in position as shown, the steam being admitted to the center of the steam chest, brings its pressure to bear on the main and auxiliary valves 4 and 7, also within the recess in the center of the chest piston. This recess encloses the main valve 4 so that this valve will move with the chest valve whenever the steam is supplied to the exhausts from each end of this chest piston; the live steam then passes through the ports a1 b1, driving the main piston 2 to the right, and the exhaust passes out through the right hand ports a and c, under the cavity in the main valve 4, to the atmosphere. As the main piston nears the right hand port, the great rocker arm 13, which is attached to the piston rod 3, brings the dog 17, in the plate 16, in contact with the valve arm 15 and moves the auxiliary valve 7 to the right, thus supplying live steam to the right of the chest valve 6, and exhausting from the left through the ports e, f. As the chest piston encloses the main valve, this valve is carried with it to the left. Steam now enters the right hand ports a b and is exhausted from the left main ports a, the engine commences its return stroke and the operation just described becomes continuous. As the piston 2 closes the main port a to the right, it is arrested on compressed exhaust steam, the main valve 4 having closed the auxiliary port b leading to that end of the main cylinder, the steam being supplied through both the main and auxiliary ports, but released through the main ports only. This discharging movement of the main piston at the termination of its stroke causes the pump valves to seat quietly, giving the pump cylinder time to fill with water, and all noise of concussion is prevented It also fills up the space between the main cylinder heads with compressed exhaust steam, released from the ends of the chest piston through one and the same ports, e e. The chest piston 6 is cushioned by cushion valves g g."

Question 546—How is the Dean Bros. steam pump constructed?

Answer—Figure 291 shows us a vertical longitudinal sectional view of the steam cylinder, same with outside movement of the valve, and Figure 292 a horizontal section through the steam chest bore and auxiliary valve. Figure 293 shows us a part of the outside valve movement in a little larger scale as in Figure 291. Figure 294 shows us a side view of same, Figure 295 a vertical sectional view through the middle of the steam cylinder. Figure 296 shows a side view of the auxiliary chest face. Figure 297 is the auxiliary

valve face with two cavities, and Figure 298 shows the auxiliary valve resting on the chest face. The letters marked in these illustrations are the same as in the description of the construction of the valve gear of the Dean Bros. pump as the manufacturer has given it, as follows: "The aux-

FIG. 291.

iliary valve F slides on the valve seat E2, and is provided on its under side with diagonal exhaust cavities d, d1. The ports b, b1 and exhaust port c are arranged in the shape of a triangle, the diagonal cavities diverge from each other, whereby the cavity d connects the ports b and c, and cavity d1 connects the ports b1 and c when the valve F is in

FIG. 292.

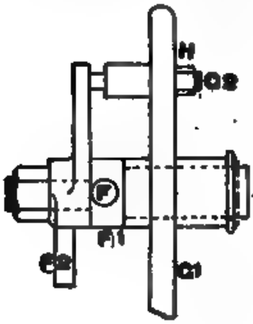


FIG. 293.

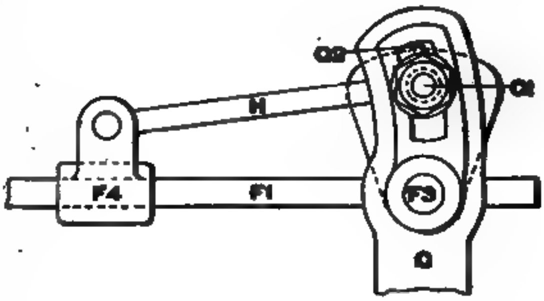


FIG. 294.

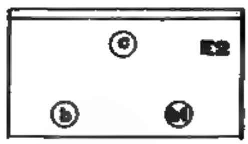


FIG. 296.

FIG. 297.

FIG. 295.

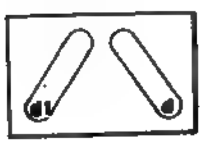


FIG. 298.

extreme positions. The operation is as follows: When the main piston moves from left to right the valve F is moved in an opposite direction, opening the port b1, admitting steam to the sub-cylinder E1 at the moment the main piston has reached the limit of its stroke, whereby the auxiliary piston is forced to the left, opening the main port and admitting steam to the steam cylinder, consequently reversing the movement of the main piston. On the return stroke of the main piston the movement of the auxiliary valve is reversed, whereby the port b1 is closed, and at the moment the main piston has reached the limit of its outer stroke the port b is opened by the valve F, causing the auxiliary piston E to reverse its motion, opening the main port and reversing the motion of the main piston. The arrangement of ports admits of a short valve with a long travel. The length of stroke of pump can be regulated by moving the stud G2 up or down in the segmental slot G1, as this varies the travel of the auxiliary valve, thereby reversing the stroke of main piston earlier or later. The motion of the auxiliary steam slide valve is continuous, like that derived from an eccentric. All other steam pumps have an intermittent motion. The ports leading to the chest piston are closed, except at the moment the main piston is being reversed; hence, there can be no 'blow through' or waste of steam in case the chest piston becomes worn. The stroke of pump can be instantly regulated by moving the stud in slot at the upper end of lever. If raised, the pump will make shorter strokes; if lowered, it will make longer strokes. The advantages of this steam valve gear are: 1. It is noiseless. 2. The auxiliary valve, having a long stroke and a rapid motion, insures a prompt reversal of the piston at the proper time. 3. There can be no waste of steam or poor working incident to the wearing of chest piston. 4. It is durable and positive. 5. The stroke of pump can be instantly changed. In this pump the slack is substituted by the lap on the auxiliary valve, which attends to it, that even the piston rod transfers its motion continuously to the valve rod of the auxiliary valve, the steam cannot enter for that purpose of moving the chest valve before the lap (which is equal to half the slack) is passed.

Question 547—How is the Hooker steam pump constructed with inside valve movement?

Answer—This valve is illustrated by the following figures: Figure 299 represents a longitudinal vertical section of the steam cylinder of the Hooker pump with inside valve movement. Figure 300 is a transverse vertical section at the

FIG. 299.

FIG. 301.

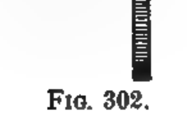


FIG. 300.

FIG. 302.

middle of the cylinder. Figure 301 shows an auxiliary valve with its attachments. Figure 302 shows the rocker shaft in length view and the rocker in side view, which in pair are forming the attachments of the auxiliary valve. The construction and action of this pump is explained by the manufacturer as follows: "A represents the steam cylinder; B the main piston; C the piston rod; D the steam chest; E the chest piston; e e the cushioned valves; F the main valve; G the auxiliary valve; H, H1 the valve rods; I the hand movement of the main valve; K, K1 the long rocker arms; L the rocker shaft; M the small rocker arm; N the yoke or center piece for connection of the steam cylinder. The parts being in position as shown in Figures 299 and 300, the steam on being admitted to the center of the steam chest brings its pressure to bear on the main valve F and on the auxiliary valve G, and also within the recess of the chest piston E; this recess encloses the main valve F, so that this valve will move with the chest piston whenever the steam is supplied to it, and exhausted from each end of this piston. The live steam then passes through the left hand port, driving the main piston B to the right, and the exhaust passes out through the right hand port, and under the main valve F to the atmosphere. As the main steam piston nears the right hand port it comes in contact with the arm K, which, being fastened to the rocker shaft L, causes the rocker shaft to oscillate. This rocker shaft projects from the chest chamber into the steam cylinder, and by means of the cam shaped short rocker arm M on it in the steam chest, moves the auxiliary valve with a constantly oscillated movement to the left, thus supplying live steam to the right of the chest piston, and exhausting from the left. As this chest piston encloses the main valve, this valve is carried with it to the left. Steam now enters the right hand port, and is exhausted from the left hand port, the engine commencing its return stroke and the operation just described becoming continuous. As the main piston closes the exhaust port to the right, it is arrested on compressed exhaust steam, the main valve having closed the auxiliary ports (which are not seen in the illustrations) leading to the end of the main cylinder, the steam being supplied through both the main and the auxiliary ports, but released through the main port only. This retarding the movement of the main piston at the termination of the strokes causes the pump valves to seat quietly, and prevent all noise and concussion in the pump, and also fills up the space between the main piston and the cylinder heads with compressed

exhaust steam, no live steam being wasted for this purpose. The rocker shafts L are ground to fit their seats in the steam chest, and the steam pressure holds them firmly thereto. There can be no leakage of steam from the steam chest into the main cylinder, nor are any stuffing boxes required. The steam from the steam chest is alternately supplied to and exhausted from the ends of the chest piston through one and the same port. The chest piston is cushioned by the cushion valves e, e1.

Question 548—How is the Cameron steam pump constructed?

Answer—The Figure 303 shows a longitudinal vertical section of the steam cylinder with the valve gear. In this figure, A represents the steam cylinder; C is the steam piston; D the piston rod; L the steam chest; F the chest piston, the right hand end of which is shown in section; G is the main valve; H is the starting bar, connected with the handle on the outside; I,I are auxiliary valves that are called here reversing valves; K,K are bonnets or heads to close the reversing valve chambers, which really represent auxiliary steam cylinders, and E,E are exhaust ports leading from the ends of the steam chest directly to the main exhaust by the auxiliary channels, the port is closed by the reversing valves I,I, and consequently not shown in the illustration.

FIG. 303.

LOCOMOTIVE TECHNOLOGY, OR CATECHISM

***Question* 1**—What is the general form of a locomotive boiler?

Answer—It is cylindrical in form and usually has a rectangular shaped fire-box at one end and a smoke-box at the other; at either end of the cylindrical portion is the front and the back flue sheet with flues extending between.

***Question* 2**—What parts are surrounded by water?

Answer—Both flues and fire-box are always surrounded by water.

***Question* 3**—Why are these parts surrounded by water?

Answer—In order to generate steam very rapidly. The greater the area of the heating surface in the fire-box and flues the greater amount of steam can be formed.

***Question* 4**—Can you describe a locomotive fire-box?

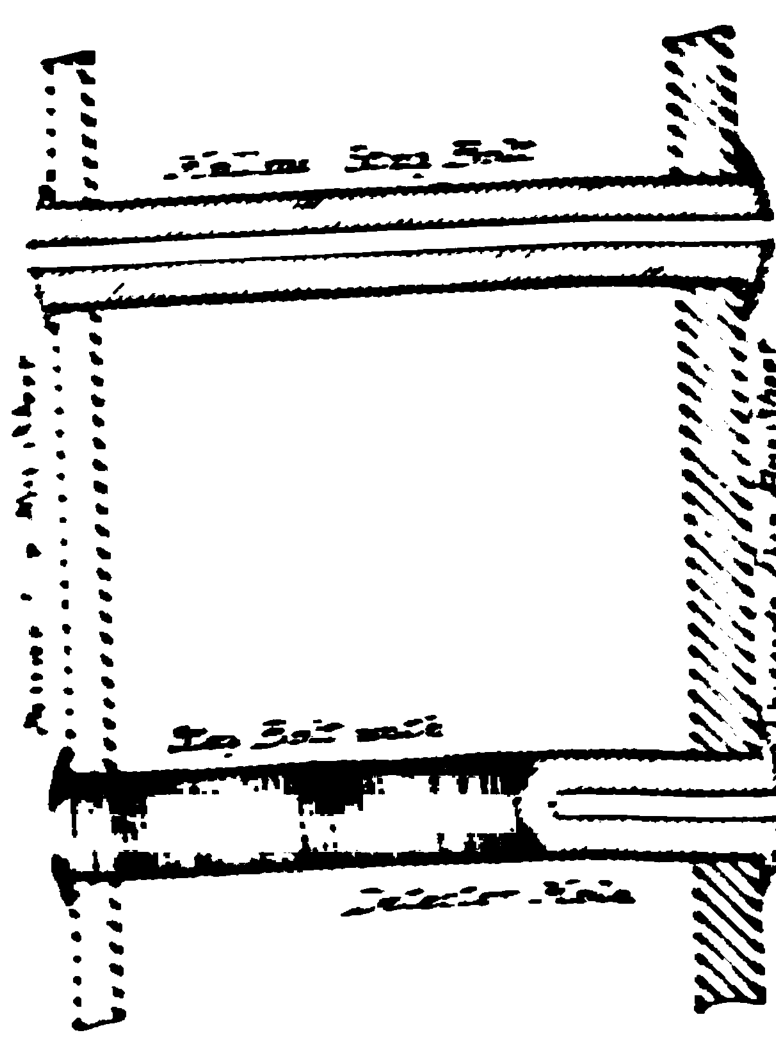
Answer—It is a rectangular shaped structure placed at the back end of the boiler.

***Question* 5**—Name the various parts of the fire-box?

Answer—Two side sheets, a crown sheet, a flue sheet and a back sheet in which the fire-door hole is located.

***Question* 6**—To what strain is a fire-box always subjected?

Answer—A crushing strain tending to cause it to collapse.



STAY BOLTS.

***Question* 7**—How are the sheets held together?

Answer—The flue sheet by the flues leading to the front end; the crown sheet by the stay-bolts, or by crown bars; the side and back sheets by stay-bolts screwed from the inside of the outside fire-box sheets and securely riveted at both ends.

***Question* 8**—Why are stay-bolts or "radial" stays now used more often than crown bars?

Answer—Because with the former it is easier to keep the crown sheet clean and they make a stronger and lighter boiler.

Question 9—What happens when mud gets baked hard on top of a crown sheet?

Answer—The crown sheet will become red hot and bag down in the spots where the mud is the thickest. This we call a mud-burn crown sheet.

Question 10—What is meant by the "leg" of a boiler?

Answer—This name is applied to the narrow water space between the inside and outside sheets of the fire-box.

Question 11—What would be the effect if the leg of a boiler became filled with mud and scale?

Answer—There would be no water against the sheets and they would become overheated and blister, as stated before in respect to crown sheets.

Question 12—Should no attention then be paid to the matter and the fire-box sheets become greatly overheated, what would be the result?

Answer—They would become red hot, be forced off the stay-bolts and an explosion would result.

Question 13—If scale and mud be allowed to fill in solid between the flues, what will happen?

Answer—The flues become overheated and either burst or collapse. In the former case the water from the burst flue will put out the fire and kill the engine, while in the latter case the flue is closed up and that much heating surface lost to the engine.

Question 14—How can mud and scale be removed from a boiler?

Answer—By frequent and thorough washing out of a boiler, special attention being given to the crown sheet, legs of boiler and center flues.

Question 15—How far should an engineman allow his engine to run without reporting her for washout?

Answer—From 600 to 2,000 miles, depending upon the conditions of the water.

Question 16—What are the fireman's duties on arrival at engine-house, previous to going out?

Answer—Draw the necessary supplies for the trip such as oil, waste, etc.; see that the lubricators, lamps, headlights, oilers, tank and sand boxes are filled. See that all the tools necessary for firing or cleaning the fire and front end are on the engine. With bituminous coal for fuel, see that it is properly broken up and, except in freezing weather, wet down; that the cab and its fittings are wiped, the ash pan cleaned and grates straight so that coal will not drop through them; and last but not least that there is plenty of water in the boiler and a good fire.

Question 17—Have you acquired the habit of comparing time with your engineman and do you insist on seeing the train orders?

Answer—I have my watch inspected at least once every week and always compare my time with that of the engineman before starting on a trip. As it is my duty to see train orders, no engineman can rightfully deprive me of that privilege.

Question 18.—Can you describe the various rules pertaining to "signals" as found in the "Book of Rules and Regulations" in force on your road?

Answer—As the American Railway Association's Standard Code of signals are unfortunately not in use on all railways it would be useless to here describe them, but the student should answer this question fully and in accordance with the Book of Rules in use on his road.

Question 19—In addition to any that you have mentioned what else do you consider a danger signal?

Answer—Any violent motion made in front of engine or train with the apparent attempt of stopping them.

Question 20—If you should discover that a fixed signal is missing or imperfectly displayed, what is your duty?

Answer—At once inform the engineman, who should stop and ascertain the cause.

Question 21—What is the use of the engine bell?

Answer—To serve as a warning of the movements of an engine or train. The rules governing the use of the engine bell are prescribed by law in each state. No engine should ever be moved, matter it not for how short a distance, without first ringing the bell.

Question 22.—Why use the terms "engineman and fireman instead of "engineer" and fireman?

Answer—The American Rules and Regulations now used as standard by most railway companies employs these terms and it is well to accustom oneself to their use.

Question 23—Why are two injectors now often placed on the right side of a locomotive?

Answer—While it has been conceded that a first-class fireman can pump the engine with the greatest economy, yet the fireman's duties are so arduous that many railroads place both injectors within easy reach of the engineman.

Question 24—Before taking an engine from the round house, what attention should be paid to the fire and fire-box?

Answer—See that there is burning coal over the entire grate surface.

Question 25—Where are you most likely to find the grates bare?
Answer—In the corners and along the flue sheet.

Question 26—Where would a bare spot on the grates do the most harm when the locomotive is started?
Answer—At the front end of the fire-box, especially without an arch, for then the exhaust through the stack draws the cold air rapidly through these bare spots on the grates and striking the flue sheet and flues cools them off rapidly, injuring them and causing leaking.

Question 27—After the flues and flue sheet, what is the next most sensitive part of the fire-box?
Answer—The side sheets, especially if they are constructed in irregular curves, that is, wider at the top than at the bottom.

Question 28—What will be the results of injury to the side sheets?
Answer—The stay-bolts will get to leaking and the sheets crack.

Question 29—What bad results ensue from leaky stay-bolts or side sheets?
Answer—The water usually sprays onto the fire lessening the heat therefrom and causing the fire to clinker badly.

Question 30—In case some parts of the grates are bare, how can fire be started there the most quickly?
Answer—Take the ash hoe or clinker bar and push some live coals to these spots then cover with fresh coal.

Question 31—What is the largest single expense of railway operation in this country?
Answer—The fuel for locomotives.

Question 32—Is this because the price of coal per ton is so great or on account of the large quantity consumed?
Answer—The latter. Most railroads own and operate mines and are thus able to obtain coal at very moderate prices, often as low as $1.00 to $1.50 per ton, but vast quantities are used.

Question 33—Who supplies this coal tó the locomotive?
Answer—The firemen.

Question 34—Who, then, can best affect a saving in fuel?
Answer—The firemen.

Question 35—Why is an understanding of the laws and principles of combustion of value to a fireman?
Answer—Because he can save both fuel and labor if he puts them into practice.

Question 36—But if the coal burns at all will it not always give out the same amount of heat?
Answer—It will not. Three times as much heat results from perfect combustion as from imperfect combustion.

Question 37—What is the chief cause of imperfect combustion?
Answer—An insufficient amount of air being admitted through the fire.

Question 38—How is the admission of air restricted?
Answer—First by the dampers; second, the ash pan being full; third, the grates being clinkered over or covered too deeply with coal to correspond with the light working of the engine; and fourth, the fire door being open so much of the time as to allow the air to be drawn principally through the door instead of through the fire.

Question 39.—In what way can a fireman save coal, make steam, and materially lighten his labors while on the road?
Answer—Keeping his fire free of ashes and clinkers so that the air has free passage through it to the green coal he puts on top.

Question 40—When can too much air be admitted to the fire?
Answer—For all practical purposes it may be said that too much air can not be admitted through the fire unless the engine is worked very lightly or has a very thin fire.

Question 41—What harm could too much air do?
Answer—Any amount beyond that necessary for combustion is not only useless, but passes through the fire-box and flues, and absorbs considerable heat before escaping through the stack to the atmosphere.

Question 42—How can the fireman best prevent the admission of too much air?
Answer—By keeping a uniform and sufficiently thick bed of fire over the entire surface of the grates. In shaking the grates while the engine is working hard, it is best to first put a good supply of fresh coal on the fire and allow it to become ignited; thus the cold air will not penetrate thin spots in the fire.

Question 43—Why will breaking up coal cause more heat per pound of coal than if fired in large chunks?
Answer—The heat is the greatest when combustion is the most rapid and that is when the most coal surface is exposed to the air.

Question 44—Then why does not the finest coal or "slack" as it is called produce the most rapid and perfect combustion?
Answer—First, because it lacks weight and much of it is drawn through the flues and thrown out the stack unburned and, second, because what remains on the grates is in such compact masses that it prevents free access of air through the bed of fire to the fresh coal supplied.

Question 45—What size has practical experience proven to be most economical?

Answer—When coal is broken uniformly to the size of an apple.

Question 46—Why should the most coal be placed in the corners and along the sides of the fire-box?

Answer—Because the draft is the strongest there.

Question 47—When and why should you wet the coal down?

Answer—To prevent dust in the cab and with very fine coal to give it added weight so that less of it will be drawn directly through the flues without being consumed.

Question 48—In putting in a fire, where should the first shovelful be placed?

Answer—Back near the door as the flame from this will tend to heat the air drawn in when the door is opened for successive shovelfuls of coal.

Question 49—To do this, when should the fireman take a good look in the fire-box for bright spots needing more coal?

Answer—Before putting in the first shovelful.

Question 50—What is the source of power in a locomotive?

Answer—Heat.

Question 51—What is steam, and how is it generated?

Answer—Steam is the vapor of water, generated by heating water above the boiling point.

Question 52—What do you understand by the pressure indicated by the steam gauge?

Answer—The pressure of steam in pounds per square inch above atmospheric pressure.

Question 53—What is meant by atmospheric pressure?

Answer—The weight or pressure of the atmosphere, which is about 15 pounds per square inch at sea level.

Question 54—What advantage is it to a fireman to watch the water level and to know the grades and conditions of the road?

Answer—To be prepared with his fire to meet the actual requirements of the service, and not to have the locomotive he is firing be blowing off going down hill and lagging for steam on the heavy pulls.

Question 55—What is the use of the safety or "pop" valves?

Answer—To relieve the boiler of any pressure above what it is designed to carry. The safety valve is automatically operated by the steam pressure which, after attaining a certain amount, presses up a stem and spring unseating a valve and thus allowing the steam to escape into the atmosphere until the pressure in the boiler has fallen slightly below that of the spring.

Question 56—Why are there two safety or "pop" valves on a locomotive?

Answer—As an additional safeguard a second "pop" or safety valve is employed, usually being set at from three to five pounds pressure above the other one.

Question 57—What is the composition of bituminous coal?

Answer—(1) Moisture 5 to 10 per cent. (2) Hydro-carbons or Volatile gases 35 to 40 per cent. (3) Fixed carbon 40 to 50 per cent, and (4) ashes, clinkers, etc., 10 to 15 per cent.

Question 58—What is carbon and from whence do we obtain oxygen?

Answer—Carbon is an element in nature found in its purest state in the diamond and possessed in large quantities in all fuels. Oxygen is derived from the air.

Question 59—What is the composition of the atmosphere?

Answer—Aside from some moisture, one-fifth oxygen and four-fifths nitrogen.

Question 60—Why is it important that a fireman should understand combustion?

Answer—Because the main duties of a fireman on a locomotive are to properly feed and care for the fire in order to supply steam in such quantities as are required, some knowledge of combustion and the properties of coal are essential to the proper performance of these duties.

Question 61—What is combustion?

Answer—Combustion is rapid oxidation or the rapid combination of oxygen with any element.

Question 62—In the combustion of coal what are the elements that are oxidized?

Answer—The fixed carbon itself and the hydrogen and carbon of the hydro-carbons contained therein. It is true that the impurities of the coal also have to be burned or combined with oxygen, but our chief interest in this fact would be to learn of the great disadvantage due thereto not only in their absorption of heat but their resultant clinkering or dirtying the fire.

Question 63—How much air is required to pass through the fire in order to properly burn one pound of carbon?

Answer—300 cubic feet or about one-half the water space contained in a large locomotive tank.

Question 64—About how much heat will one pound of carbon give out if perfect combustion takes place?

Answer—Nearly 15,000 heat units.

Question 65—What is a heat unit?
Answer—The amount of heat required to raise one pound of water one degree in temperature.

Question 66—How many pounds of water will 15,000 heat units cause to be evaporated into steam?
Answer—About 15 pounds.

Question 67—With imperfect combustion, how much heat will one pound of carbon produce?
Answer—About 4,500 heat units.

Question 68—How much water would this evaporate?
Answer—Less than 5 pounds.

Question 69—Explain the difference between perfect and imperfect combustion of carbon?
Answer—To obtain perfect combustion each particle of carbon (C) must unite with two particles of oxygen (O) forming carbonic acid gas. To use the cymbals, $C+2O=CO_2$, produces nearly 15,000 heat units. Should the supply of air be too small for obtaining two parts of oxygen for every part of carbon, one part of each would combine producing carbonic oxide gas. $C+O=CO$, producing less than 4,500 heat units.

Question 70—Does this comparison between complete and partial combustion hold true with regard to soft or bituminous coal?
Answer—Yes, but with considerably greater differences due to the fact that as stated before, bituminous coal generally contains about 40 per cent of hydro-carbons, which if not properly consumed produce still greater loss.

Question 71—What must be done to burn these hydro-carbons or volatile gases?
Answer—Not only must there be sufficient air admitted to furnish the necessary amount of oxygen, but also this air must be heated to a temperature high enough to produce combustion, which temperature is about 1800 degrees.

Question 72—Then what are the two principal sources of heat in the burning of bituminous coal?
Answer—That produced by the burning of the volatile gases which gives us the flame and that generated by the combustion of the fixed carbon, which burns with an intense incandescent heat, like coke.

Question 73—Has a locomotive a natural or a forced draft while working?
Answer—A locomotive has a forced draft either with the blower on or while working.

Question 74—How is such "forced" draft produced?

Answer—By having the exhaust from the cylinders or the jet of steam from the blower go through the stack pulling with it the air or gases in the front end. This partial vacuum is supplied by the rush of air through the grates, fire-box and flues.

Question 75—What is the advantage of this forced draft?

Answer—The rapidity of combustion is very greatly increased by more air being drawn through the fire, hence more steam is produced by this more rapid combustion.

Question 76—How can you indicate this?

Answer—A locomotive boiler at times of the severest working of the engine generates from 7 to 10 times as much steam as the same boiler would with a natural draft only.

Question 77—In what does the fuel of a locomotive consist?

Answer—It consists of both coal *and air,* for without the oxygen of the air there can be no combustion or burning.

Question 78. Can too much air be admitted through the grates and fire?

Answer—Whenever an engine is working hard, we can safely say "no," but with a light and clean fire too much air will not only pass through the fire-box and flues unused but will absorb a great deal of heat in its passage and thus produce a loss.

Question 79—What is the temperature of the gases by the time they have reached the front-end there to be ejected through the stack?

Answer—From 400 to 950 degrees, depending upon the working of the engine and the fierceness of the draft.

Question 80—Then if too much air be admitted to a light or thin fire what heat is lost?

Answer—The heat required to raise such surplus air from the temperature of the atmosphere to a point somewhere about 700 degrees on an average.

Question 81—What is the lightest combustible known?

Answer—Hydrogen.

Question 82—Does bituminous coal contain this gaseous element?

Answer—Yes in very large quantities, but in combination with carbon it is termed hydro-carbon.

Question 83—What ordinary liquid is composed almost entirely of hydrogen and burns with the most intense heat known?

Answer—Alcohol, whose flame is almost smokeless.

Question 84—If sugar (nearly all carbon) is burned with alcohol what is the result?

Answer—A long smoky flame unless plenty of air at a high temperature is admitted to the flame.

Question 85—In what way can it be shown that only by the admission of sufficient air can combustion be made complete and smoke prevented?

Answer—By closing the air openings below the burner of any lamp. If all air be excluded, the lamp will go out, and the amount of smoke made by the lamp will depend upon how much of the needed air is excluded.

Question 86—What, then, is black smoke?

Answer—Black smoke is a mixture of gases and carbon—the greater part of it being carbon or unconsumed fuel.

Question 87—In what condition should the fire in a locomotive be to completely burn these hydro-carbon gases?

Answer—It should have a very high temperature.

Question 88—What is the appearance of the fire when it is at a very high temperature?

Answer—A brilliantly incandescent or "white" heat.

Question 89—How can black smoke be prevented?

Answer—To a large degree by careful firing and also by the aid of an arch and certain other proven devices.

Question 90—What are the advantages of the arch in a locomotive fire-box?

Answer—It keeps the air and the gases in the fire-box for a greater length of time, it protects the flue-sheet from the cold air caused by opening the fire-box door or from holes in the fire and it maintains a more uniform temperature in the fire-box. Even when the fire is knocked out, the heat from the arch prevents too sudden contraction of the flues and flue-sheet. An arch also prevents the honey-combing of the flue-sheet to a degree.

Question 91—What are the advantages of an arch from a practical standpoint?

Answer—It is hard on the portion of the side sheets against which it rests and when flues are leaking it is impossible to calk them without removing the arch or else waiting a long time for it to cool.

Question 92—What are the objections to allowing an engine to "blow off" or steam to escape at the safety valves?

Answer—It is a waste of steam which means a waste of fuel, also the noise is very objectionable at the times and places where it is most likely to occur.

Question 93—How much steam is wasted each minute the pop is open?

Answer—About 15 pounds or one shovelful; yet no fireman who might allow such a waste at the pops would think of throwing a shovelful of coal onto the ground each minute, though the loss would be no greater.

Question 94—What effect on combustion has opening and closing of dampers?

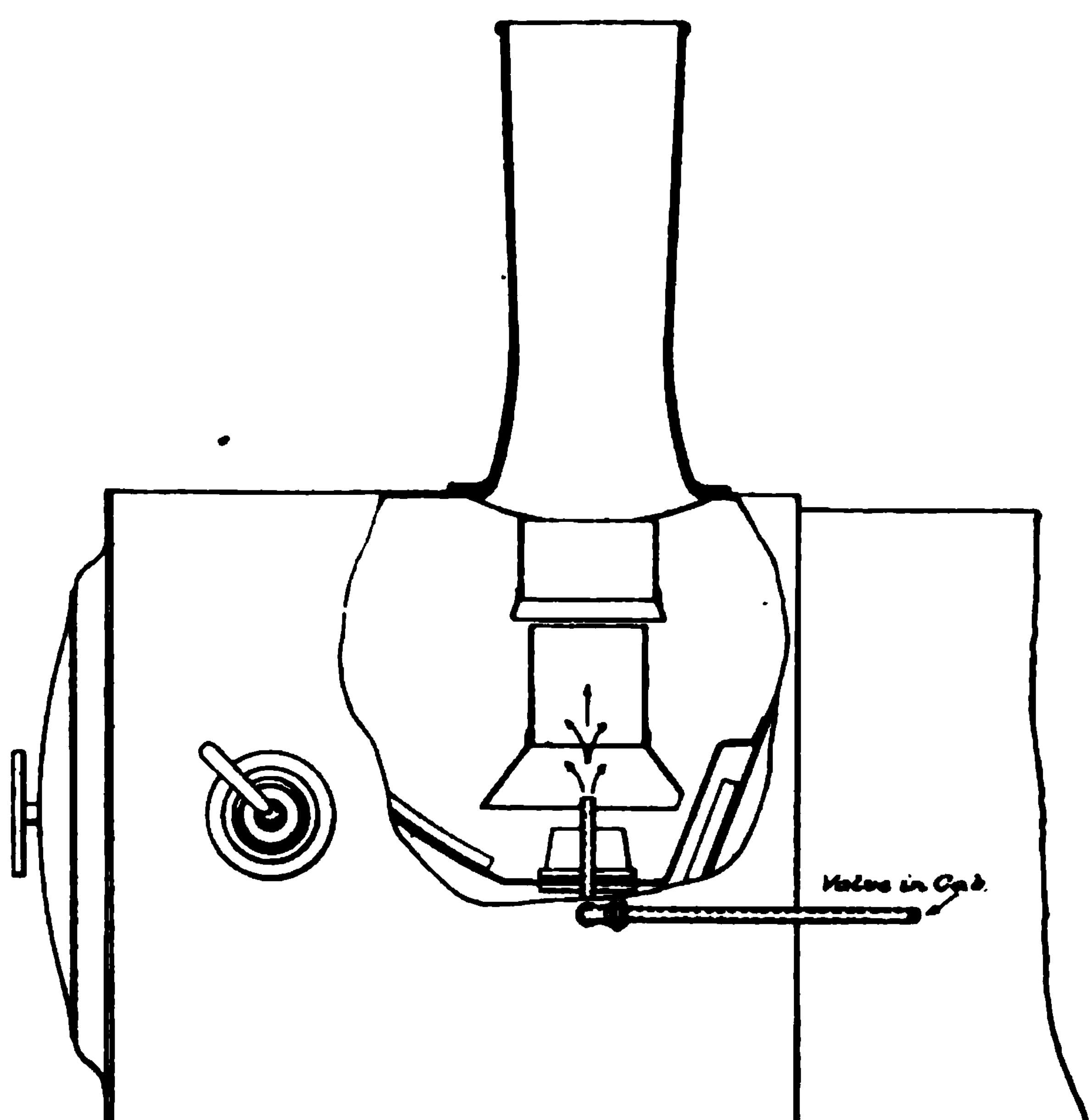
Answer—Opening the dampers increases the air admitted through the grates and fire and increases combustion; closing the dampers has the opposite effect.

Question 95—What is the effect of closing the dampers when a locomotive is working hard?

Answer—It is likely to cause leaky flues and fire-box.

Question 96—How can you prove the theory that the mixing of air with the fire-box gases increases combustion and prevents black smoke?

Answer—Do what you would if you were going to examine your fire, namely: insert the coal scoop in the fire-box door and air will be deflected down onto the fire, brightening it and consuming so much of the smoke that you can readily see all parts of the fire and fire-box.



BLOWER ARRANGEMENT IN FRONT END.

Question 97.—What is the "blower?"

Answer—A valve on the boiler head within easy reach of the fireman admits steam to a pipe leading to the smoke box or "front end," the pipe pointing up toward the stack and thus producing an action similar to the exhausts ot the engine but with very much less steam.

Question 98—How can a blower be used to the injury of the boiler?

Answer—By putting it on too strongly while the fire is being cleaned or knocked out, or when the door is open. In such cases cold air is drawn through the fire-box and flues, producing sudden contraction.

Question 99—What good practice is often followed to keep cold air from the fire-box and flues after the fire has been knocked out?

Answer—Some roads have jacks in the roundhouses with tight dampers that may be closed, others put a cover over the top of the locomotive stack to stop the draft. In both cases the ash pan dampers are of course closed.

Question 100—If the comparative coal records of your road are made on the locomotive mileage basis, would you make a good or a poor record with a very light train?

Answer—A good record, for you could run more miles to the ton of coal than with a heavy train.

Question 101—Give examples to illustrate.

Answer—(1) Suppose you went over a 100 mile division with an engine and caboose, burning 2 tons of coal: You would have run 50 miles per ton of coal. (2) Suppose you had a heavy train and burned 10 tons of coal you would only be making 10 miles per ton of coal.

Question 102—If your comparative records are shown on the ton-mileage basis, how would this be?

Answer—The heavier the train, up to the full economical rating, the better would be your record.

Question 103—Give examples to illustrate.

Answer—Take the two cases above cited. (1) Suppose the caboose weighs 20 tons. 20 (tons) × 100 (miles) =2,000 ton-miles for accomplishing which you burned two tons of coal; hence you only made 1,000 ton-miles per ton of coal. (2) Suppose you hauled 1,500 tons over this division, your ton-miles would be 1,500 (tons) × 100 (miles)=150,000 ton-miles. If you burned 10 tons of coal to do this, you will have made 15,000 ton-miles per ton of coal.

Question 104—In a locomotive boiler how much water should be evaporated to every pound of coal?

Answer—*Theoretically,* about fourteen pounds; *practically,* from six to nine pounds of water, according to the efficiency of the boiler and the quality of the coal. It should not be overlooked that with the same boiler and the same quality of coal a good fireman may attain the higher figures while a poor fireman may fall below the ratio of six.

Question 105—Why can a locomotive be fired much more intelligently and economically if the fireman watches closely the water level?

Answer—Because demands upon the boiler depend just as surely upon the water level as they do upon the position of the reverse lever. A fireman in a few days learns to increase his energies as soon as he sees the lever dropped, but many a man fails to continue his exertions when he sees the lever hooked up shorter and the injector feed increased, as necessary, due to the water level having become low.

Question 106—Do you consider it for your interest to be economical in the use of fuel and supplies?

Answer—Economy is a most important matter in the success of locomotive operation. A careless fireman or engineman can waste more each trip than the amount of his wages. Careful economy should be practiced in all things pertaining to the locomotive.

Question 107—What is the difference between a straight and a diamond stack?

Answer—These are named from their appearance.

Question 108—Can you describe a diamond stack?

Answer—A diamond stack is always used with a short smoke box. There is a netting near the top of the stack and a cone just under the netting.

Question 109—What is the use of the cone?

Answer—To break up the cinders and also prevent their escape into the air as live sparks. It also distributes the draft more evenly to all parts of the netting.

Question 110—Is a petticoat pipe ever used with a diamond stack?

Answer—Yes. Its purpose is to regulate the draft through the flues and to cause the exhaust to better fill the stack.

Question 111—Where a straight stack is used what kind of a smokebox does the locomotive have?

Answer—A long straight shell from 5 to 7 feet long and of the same diameter as the smallest ring of the boiler. This form of smokebox is often termed the "extended front end."

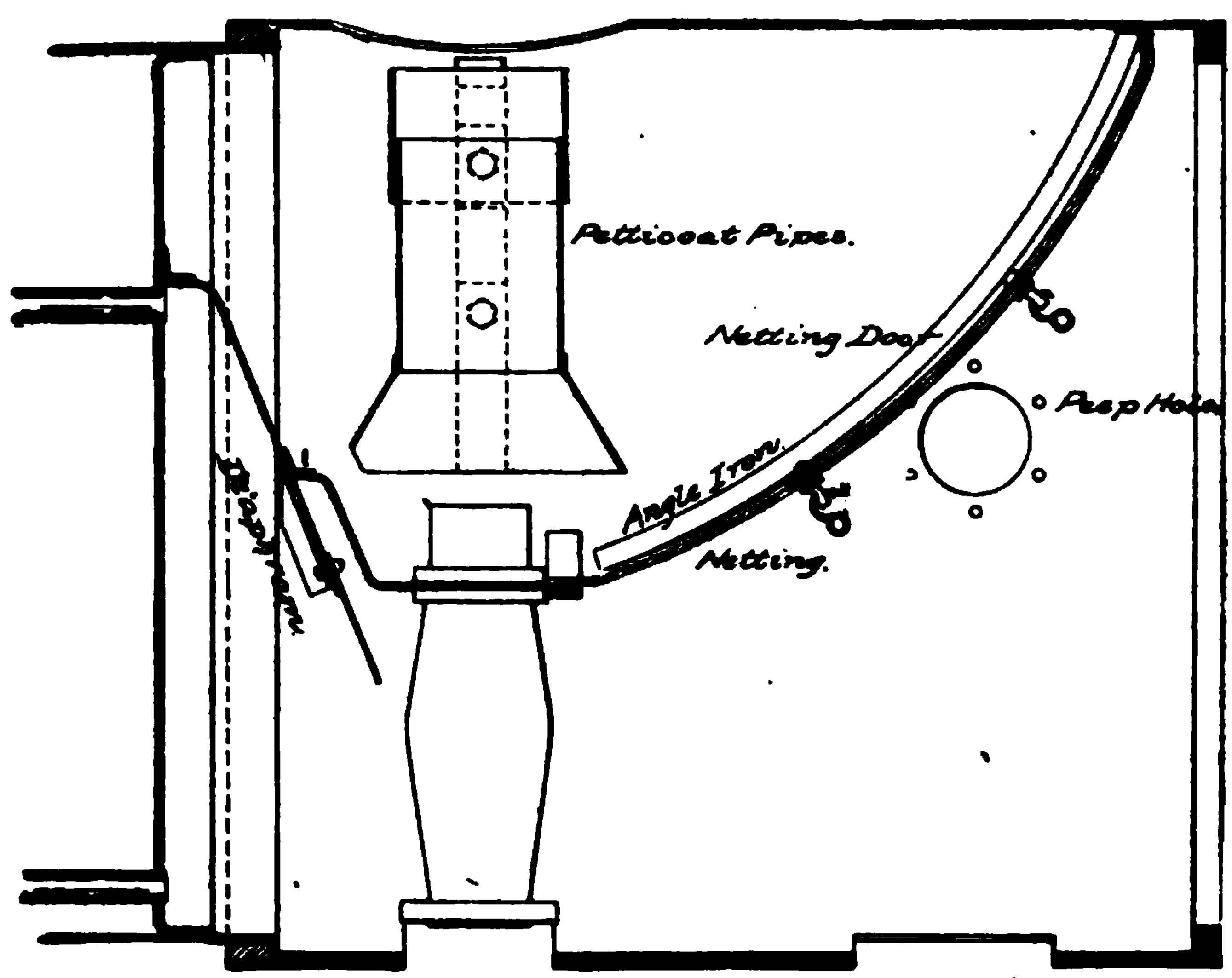
Question 112—What is the purpose of the extended front end?

Answer—It was originally designed as a receptacle to hold the sparks and cinders until a convenient place was reached for dumping them; also contained therein are the various draft appliances.

Question 113—Describe these draft appliances in the extended front end.

Answer—A solid plate called the Diaphram extends from above the top flues towards the bottom of the arch and usually at an

angle with the flue sheet. The lower edge of this plate is usually from 14 to 20 inches above the bottom of the arch. This plate is for the purpose of causing a more equal draft through all the flues. The lower edge of the diaphram is made adjustable so as to be raised and lowered a few inches with ease. This diaphram also helps to clean the cinders out of the front end, for it should be remembered that it is no longer thought advisable to retain them until the front end is filled up and often the draft impaired, but rather to break them up, destroy their life and thrown them out of the stack.



DRAFT APPLIANCES IN MASTER MECHANICS' FRONT END.

The netting extends from the diaphram to the upper front portion of the arch, the exhaust pipe and nozzle projecting through and supporting the center part of the netting. The netting breaks up the sparks and prevents their escape when they first come alive from the fire-box. Above the nozzle is generally placed a single or double petticoat pipe for the purpose of increasing the draft and causing the exhaust to properly fill the stack. At the bottom of the front portion of the arch is usually a cinder valve to remove cinders remaining there after the trip.

Question 114—What is the modern tendency with respect to the various front-end devices?

Answer—To do away with many of them. It is claimed that all cinders should be thrown out and hence no cinder valve re-

quired; also that the diaphram and petticoat pipes should be eliminated.

Question 115—What is one objection to the cinder valve?

Answer—It often leaks air into the front end, thus reducing the draft and causing the cinders therein to burn and injure the smokebox by warping it out of shape.

Question 116—Has the stack anything to do with the engine's steaming qualities?

Answer—Yes, greatly; engines will not steam with too short a stack nor one too large.

Question 117—With the very large boilers of modern locomotives why are the stacks made so short?

Answer—Because the top of the stack must be low enough to clear bridges and roundhouse doors.

Question 118—Then how is the effect of a long stack accomplished?

Answer—By a stack extending down into the smoke arch for perhaps a distance greater than its external projections.

Question 119—With a tapered stack, where should the smallest diameter or "choke" be?

Answer—Near the base of the stack and at a point where the steam from the exhaust nozzle strikes the walls of the stack.

Question 120—How can you determine this practically?

Answer—When the front-end is open you can set a torch in the center of the nozzle and see if the shadow cast by the petticoat pipe strikes the stack at the choke.

Question 121—What is the effect of changing the diameter of the stack?

Answer—To a degree it acts similarly to altering the size of exhaust nozzle. A larger tip can be used with a small stack than with a large one.

Question 122—Suppose you had a locomotive having a boiler with tender and leaky flues, what would you do if you were going to clean the fire and tie the engine up over night at an outside point where there were no boilermakers?

Answer—Keep the fire-box at as nearly a uniform temperature as possible on the road and the steam pressure in the boiler without excessive variation and old tender flues will do the best.

Question 123—How can this be done practically?

Answer—If there were a brick arch in the fire-box, throw a few pieces of wood up on top of it before you start to clean the fire. If no arch, as is usually the case with engines having leaky flues, have some sticks of wood or some brightly burning coal in the fire-box. Now open the blower valve just as

little as necessary to take up the smoke. This will prevent pulling cold air through the flues. Clean off the grates, always pushing some of the brightly burning coal back onto the portion of the grates just cleaned. When you have cleaned the fire, scatter the live fire and put in fresh coal leaving about three inches of fire on the grates to burn out slowly after the engine is put away. The temperature of the fire-box will thus fall slowly and the flues cool off evenly. Always close the dampers when an engine is left.

Question 124—How should this boiler be fired and "pumped" on the road?

Answer—Supply the boiler with water as regularly as possible and keep a bright fire of uniform thickness, allowing no holes to be formed. Cold air either from holes in the fire or from the open fire-box door will cause flues to leak most quickly.

Question 125—What is the object of hollow stay-bolts or of "detector holes" in stay-bolts?

Answer—So that they will give immediate notice by showing a leak when the stay-bolt breaks.

Question 126—Of what other use are the holes in hollow stay-bolts?

Answer—Air in small streams is admitted through them to the fire-box and being heated it readily combines with the gases and aids in their more complete combustion.

Question 127—How else is air often admitted above the fire for the combustion of the gases?

Answer—By side and back flues connecting the two inside and outside fire-box sheets and located just above the fire; also by holes in the fire-box door.

Question 128—What good effect is produced by opening the fire-box door when an engine is working steam?

Answer—By partially opening the door, black smoke and popping are prevented.

Question 129—What bad effect is produced if the door is left wide open with the engine working?

Answer—It causes the flues and stay-bolts to leak.

Question 130—Why does cold air cause flues to leak?

Answer—Fire expands the flues and flue-sheet and when cold air strikes them, the flues being thinner than the sheet, they contract the more rapidly and leave an opening between the flue and the hole in the sheet.

Question 131—Why does putting a great quantity of cold water into a boiler have the same effect?

Answer—For a similar reason and also because the flues contract in length when cooled and tend to pull out of the flue-sheet.

Question 132—When the most of the fuel is burned in the forward part of the fire-box, what does it indicate?

Answer—That the greater amount of draft is through the bottom flues.

Question 133—When the most of the fuel is burned in the back of the fire-box, under the door, what does it denote?

Answer—That the greater draft is through the top flues.

Question 134—How can these irregularities be equalized?

Answer—By adjusting the diaphram in the front end.

Question 135—How often should the grates be shaken?

Answer—Often enough to keep the ashes and clinkers from forming on the grates. About once or twice an hour is sufficient with ordinary coal. It is best to shake them often and not to hard; every 15 miles on freight and every 25 miles on passenger engines is a fair average.

Question 136—If the grates get clinkered how can it be told by the fireman?

Answer—The fire will not burn brightly and too, there will be a much harder pull on the fire-box door. As the air can not come up through the grates it makes all the stronger effort to get through the door.

Question 137—Name one thing that will cause the grates to clinker rapidly.

Answer—Long and hard use of the blower.

Question 138—What are your views in regard to keeping an engine clean?

Answer—While the railroads differ in their requirements in this matter, it can be safely said that one of the most creditable things that can be said of a fireman is that he always keeps a clean engine both inside and outside the cab.

Question 139—Is it advisable to put a fire in an engine while starting a train?

Answer—No. It should always be the aim of the fireman to put sufficient coal on the fire before starting to last until the lever is hooked up and consequently the exhaust less sharp.

Question 140—Can this plan be followed without the co-operation of the engineman?

Answer—Most surely not. An engineman that will start a heavy train without a moment's notice to the fireman will discourage the most skillful of firemen.

Question 141—How should the cab and signal lamps, oil cans and lanterns be kept?

Answer—They should all be kept clean, free from leaks and filled before starting on any trip.

Question 142—Are the signal lamps of much importance?
Answer—The safety of trains depend much upon the proper burning of signal lamps.

Question 143—How can the cab, cab windows and brass work in the cab be kept clean?
Answer—By frequent washing, cleaning and wiping. The paint of the cab should be washed with soap and water then polished with clean dry waste at least twice a month. The windows should be wiped off before every trip, washed with tripoli and water and polished at least once a week. The brass work should be polished with oil and tripoli once a week and wiped off daily. A little acid and water, or lemon juice if applied at first will make cleaning easier.

Question 144—How should the boiler head be attended to?
Answer—Scrape off all gum and scale and polish with stove blacking or paint with gas house tar while the boiler is slightly warm.

Question 145—What should be done with surplus steam in case of sudden and unlooked for stoppage or slow down?
Answer—It should be blown back into the tank—not sufficiently strong to injure the tank-hose—and the tank water heated but not higher than blood-heat.

Question 146—Is warm water in the tank of considerable advantage in making steam rapidly?
Answer—Yes, indeed; in the same way that a boiler full of hot water is a greater reservoir of stored heat. Careful experiment has proven that the same locomotive will generate one per cent more steam for every eleven degrees that the water in the tank is heated. Thus heating water from 57° to 90° would effect a saving of three per cent.

TEMPERATURE OF BOILING WATER AND STEAM AT VARIOUS PRESSURES.

Pressure per Square In. above Atmosphere.	Corresponding Temperature.	Pressure per Square In. above Atmosphere.	Corresponding Temperature.
0 pounds	212° Fahr.	110 pounds.	344° Fahr.
10 "	240° "	120 "	350° "
20 "	259° "	130 "	355° "
30 "	274° "	140 "	361° "
40 "	287° "	150 "	366° "
50 "	298° "	160 "	370° "
60 "	307° "	170 "	375° "
70 "	316° "	180 "	380° "
80 "	324° "	205 "	390° "
90 "	331° "	235 "	401° "
100 "	338° "		

HEAT REQUIRED TO CONVERT HOT WATER INTO STEAM AT VARIOUS PRESSURES AND TEMPERATURES.

Pressure per Square Inch above Atmosphere.	Temperature of the Steam.	Units of Heat * per Pound of Water Converted into Steam.	
		† Latent Heat.	Total Heat from 32° to pressure named.
0 pounds.	212° Fahr.	966 Heat Units.*	1146 Heat Units.*
15 "	250° "	937 " "	1157 " "
20 "	259° "	931 " "	1160 " "
25 "	267° "	926 " "	1163 " "
30 "	274° "	920 " "	1165 " "
45 "	292° "	908 " "	1171 " "
60 "	307° "	897 " "	1175 " "
75 "	320° "	888 " "	1179 " "
100 "	338° "	876 " "	1184 " "
125 "	353° "	865 " "	1189 " "
150 "	366° "	856 " "	1193 " "
175 "	377° "	848 " "	1196 " "
200 "	388° "	840 " "	1200 " "

Question 147—Then why not heat the water in the tender up to 212°, or the boiling point?

Answer—First, because it would ruin the paint on the tank; second, because if the temperature of the water is much above blood-heat, about 100°, it will not condense enough steam in the injectors to cause them to work properly.

Question 148—If the fire should get low at stations or at sidings, how would you proceed to build it up and still avoid black smoke?

Answer—The coal should be well broken up and fired in small quantities at frequent intervals and scattered well over the fire, the blower being open slightly to prevent smoke, the door also being left slightly open if found necessary.

Question 149—What would you call abuse of a boiler?

Answer—Any thing causing sudden changes in the temperature of the fire-box such as improper pumping, heavy firing or tearing a hole in the fire.

Question 150—What is meant by the expression "turning the fire?"

Answer—This is an expression common among enginemen and means the tearing of holes in the fire or baring of portions of the grate caused by working an engine too hard or slipping an engine with a light fire.

* A heat Unit is the amount of heat required to raise one pound or water from 32° Fahr. to 33° Fahr.
Latent heat is the amount of heat that is absorbed or disappears in converting water into steam at the same pressure and temperature.

Question 151—With a light fire, if the engine should suddenly slip, how can damage to the fire be prevented?

Answer—By quickly opening the fire-box door, thus permitting the air to be drawn over the fire instead of through it, for the instant.

Question 152—What advantages are claimed for a large grate surface?

Answer—The rate of combustion per square foot of grate area is reduced, better mixture of oxygen and gases is permitted, and a poorer and finer grade of coal can be used than is possible with small grate surface.

Question 153—Why are all wide fire-boxes made shallow?

Answer—The deep fire-box is limited in width by the frames and a fireman cannot throw coal into a box longer than ten or eleven feet. Hence to get the large grate area the shallow fire-box, always above the frames and sometimes above the drivers, is used.

Question 154—When the destination terminal is reached, what are the fireman's duties?

Answer—Leave a good fire partly burned down, close all dampers, remove signal lamps or flags, and at night leave headlight burning and one red light on rear of tank for protection until the engine is dispatched.

Question 155—What is the cause of the drumming noise when an engine is shut off, and how can it be avoided?

Answer—It is claimed to be numerous explosions of unconsumed gas and can and should be prevented by closing the dampers or opening slightly the fire-box door. This noise is very obnoxious to most people and around telegraph offices and depots prevents the transaction of necessary business.

Question 156—Why are two fire doors placed in the very wide fire-box boilers?

Answer—So that the fireman can more easily spread the coal over the grate in an even layer.

Question 157—What is the principle upon which an injector works?

Answer—The velocity of steam from the boiler is imparted to a jet of water and by the latter condensed. The *moving* or *kinetic* energy of this stream overcomes the *standing* or *static* energy on top of the check and the water enters the boiler.

Question 158—What two classes of injectors are there in common use?

Answer—Lifting and non-lifting injectors.

Question 159—Explain the lifting injector.

Answer—A lifting injector is one having a priming attachment. which acts the same on the water in the tank that the exhaust of an engine does in "pulling" air through the fire-box and flues. A jet of steam directed out of the overflow pipe causes a vacuum in the water supply pipe and the atmospheric pressure upon the water in the tank forces the water through the feed pipe to the injector and out the overflow. This class of injector can be placed above the level of the water supply. *

MONITOR INJECTOR.—SECTIONAL VIEW

LIST OF PARTS.

1	Body (back part)	16	Jet Valve Gland	32	Stop Ring
2	Body (front part)	17	Jet Valve Lever Handle	33	Overflow Nozzle
3	Body Screw	18	Jet Valve Top Nut	33a	Overflow Chamber with Nut
4	Yoke	18a	Jet Tube	34	Heater Cock Check
5	Yoke Gland	18b	Lifting Nozzle	35	Heater Cock Bonnet and Nut
6	Yoke Packing Nut	19	Water Valve	36	Heater Cock Spindle
7	Yoke Lock Nut	19a	Eccentric Spindle	37	Heater Cock T Handle
8	Steam Valve Disc and Nut	20	Water Valve Bonnet	38	Coupling Nut-Steam End
9	Steam Valve Spindle	23	Water Valve Lever Handle	38a	Tail Piece-Steam End
10	Steam Valve Handle	25	Steam Nozzle	39	Coupling Nut-Water End
11	Steam Valve Rubber Handle	26	Intermediate Nozzle	39a	Tail Piece-Water End
12	Steam Valve Top Nut	27	Condensing Nozzle	40	Coupling Nut-Delivery
13	Jet Valve Disk and Nut	29	Delivery Nozzle	40a	Tail Piece-Delivery End
14	Jet Valve Spindle	30	Line Check	41	Water Chamber
15	Jet Valve Bonnet and Nut	31	Line Check Valve	42	Vacuum Chamber

Question 160—Explain the non-lifting injector.

Answer—A non-lifting injector has no such attachment and must be placed below the level of the water supply so that the water will flow to it.

Question 161—Why will a lifting injector not prime with a leak above the water line?

* Another theory of the working of an injector is as follows: The pressure of the steam at the instant it strikes the water at the large end of the combining nozzle is sufficient to overcome many times the same pressure per square inch at the small end of the combining nozzle and hence forces the water into the boiler against the boiler pressure on top of the check valve, the operation being explained on the same principle that the large steam piston of a pump when connected to a smaller water piston will increase the water pressure above the steam pressure used to operate the pump.

Answer—Because this leak, if sufficiently large, will destroy the vacuum. If the leak is below the water level, the result is not so serious.

Question 162—If an injector will not prime how would you proceed to locate the trouble?

Answer—First, see that all valves are open to the tank, that there is water in the tank and that the strainer is not partly stopped up or the hose kinked; then, look for a leak in the feed pipe.

Question 163—If an injector primes well, but breaks when steam is turned on full, where is the trouble most likely to be?

Answer—(1) checks stuck down, (2) branch pipe stopped up, (3) worn or loose combining tubes, or (4) not sufficient water supply.

Question 164—Why will not an injector prime when boiler checks leak or stick up or injector throttle leaks badly?

Answer—Because they prevent the formation of a vacuum in a lifting injector and the flow of water to a non-lifting injector, and no injector will work without the water supply is ample.

Question 165—If the injector throttle leaks, how can it be known?

Answer—The escape of almost dry steam from the overflow when the injector is not working.

Question 166—How can you tell if the boiler check is leaking or stuck up?

Answer—When the injector is not working steam and hot water will escape from the overflow, also from the "frost cock."

Question 167—Where is the frost cock located and what is its purpose?

Answer—It is a small pet cock located in the supply pipe at its lowest point between the injector and the boiler check. Its purpose is to drain this pipe of water in cold weather when the injector is not working.

Question 168—If the primer valve leaks, will a lifting injector prime?

Answer—Yes, because it is the steam from this valve that causes the priming.

Question 169—Will this leak prevent the injector from working?

Answer—No, but some water will be wasted from the overflow in case of a bad leak.

Question 170—Why will an injector not work when the air cannot get into the tank as fast as the water is drawn out?

Answer—Because the atmospheric pressure is depended upon to cause the water to flow to either a lifting or a non-lifting injector. There are generally air holes about the man-hole or elsewhere in the top of a tank that serve to admit air except in severe cold weather, when they may be frozen up and make it necessary to slightly open the man-hole cover.

Question 171—Will an injector work when either the water is too hot or else not of sufficient quantity to condense all the steam?

Answer—No, or at best it will break frequently.

Question 172—In taking down a tank hose on a tank having a syphon connection, how would you stop the flow of water?

Answer—By first opening the small pet cock at the top of the syphon, thereby admitting air and destroying the syphon action.

Question 173—What is the principle of the so-called "re-starting" injectors?

Answer—This form of injector has large overflow openings and should the injector break, the air and steam will blow out of the overflow pipe, thus maintaining sufficient vacuum in the injector feed pipe to again draw the water to the injector if there is any water left in the tank.

Question 174—Is the combining tube of an injector fixed or movable?

Answer—In most of the modern high steam pressure injectors it is fixed.

Question 175—If the injector should entirely fail to work on the road what should you do?

Answer—Get to the nearest siding if possible so as to clear the main track. Save what water and steam you have and knock the fire and clean it out of the ash pan before the water gets below a safe limit in the boiler. If the weather is cold, drain all pipes and blow them out with steam before all pressure is gone, finally letting all water out of boiler if necessary.

Question 176—How is the best way to handle the injector steam throttle on the boiler?

Answer—Most injectors will work best when this valve is only opened sufficiently to take up all the water from the overflow.

Question 177. In making station stops, how is the best manner of working an injector?

Answer—Leave the injector on when the engine is shut off and the stop being made, as the fire is still bright and will likely cause waste at the pop valves if you do not. Just before the train is to be started, shut off the injector and leave it shut off until the fire is again burning brightly and the reverse lever hooked up enough so that there is less danger of the water raising in the boiler.

Question 178—What is the great disadvantage in working wet steam?

Answer—At least, the water washes the oil off the valves, valve-seats and the walls of the cylinders. With bad water, the lime and sediment will adhere to these parts and cause groaning and cutting.

Question 179—Is it safe to run by the water-glass unless the water therein is in sight and bobbing up and down with the motion of the engine?

Answer—It is not. One or both of the water glass cocks may be stopped up.

Question 180—What is the highest part of a locomotive boiler directly subject to the fire-box heat?

Answer—The crown-sheet, which is either level or sloping upwards four or five inches toward the front. Hence the front is generally considered the highest point.

Question 181—Are the water glass and the gauge cocks always located the same number of inches above the crown-sheet on all classes of engines?

Answer—Unfortunately they are not. The bottom gauge cock should not be less than three inches above the crown-sheet, the bottom water glass cock the same, but in some old class locomotives this is very much less.

Question 182—Do you understand why water must always be kept in contact with the crown-sheet and other fire-box sheets?

Answer—Because the heat in the fire-box with a bright fire is so intense that the sheets would otherwise get red hot and their stiffness and strength be impaired.

Question 183—At 200 pounds boiler pressure what pressure is there on each square foot of the fire-box and crown sheet?

Answer—Nearly 15 tons.

Question 184—What is the total pressure on the fire-box of a large locomotive boiler?

Answer—Over 3,000 tons.

Question 185—What is the difference between "priming" and "foaming" of a boiler?

Answer—"Priming" is caused by having too high a water level in the boiler; "foaming" is the result of foreign substances such as animal oil, soap, vegetable matter, etc.

Question 186—What is the danger in either case?

Answer—Besides impairing lubrication in steam chests and cylinders, as previously explained, there is great danger of knocking out cylinder heads, cutting valves, breaking packing, rings, etc.

Question 187—What would you do in case of foaming?

Answer—Open the cylinder cocks first, then shut off carefully and ascertain the true water level by letting it settle in the glass.

Should the water drop out of sight in the glass, open the throttle enough to raise the water over the crown sheet and put on the injectors. Open the blow off cock as soon as there is water enough in the boiler. It is sometimes necessary to blow a boiler off repeatedly and supply a great deal of fresh water in the meantime.

Question 188—If you found that there was oil in the tank what would you do?

Answer—Put the heaters on the tank and get to the nearest water station, take down both tank hose, let all the water out of the tank and flush the tank thoroughly.

Question 189—Is any more water used when a boiler is priming or foaming?

Answer—A great deal, for one cubic inch of water has the same amount of moisture as one cubic foot of steam at atmospheric pressure.

Question 190—What can you deduce from this?

Answer—That to effect economy too high a water level must not be kept and the boiler must be frequently washed out and kept free from foreign matter that causes foaming.

Question 191—Should an engine ever be slipped to get water out of the steam passages?

Answer—It should not. Open the cylinder cocks and start the engine slowly.

NAMES OF PARTS.

A—Oil Reservoir.
F—Condenser.
O—Filler Plug.
G—Drain Plug.
D—Water Valve.
EE—Feed Regulating Valves to Right and Left Cylinders.
L—Feed Regulating Valve to Air Pump.
ZZZ—Automatic Safety Valve.
JJJ—By Pass Valves.
WW—Couplings to Cylinders.
R—Couplings to Air Pump.

SIGHT FEED LUBRICATOR.

Question 192—What is the principle upon which the sight feed lubricator operates?

Answer—The lubricator consists of an oil reservoir (A) in the main body with a steam condensing chamber (F) above it, and usually three sight feed gauge glasses (H. K.) with connections to the top and bottom of the oil reservoir. Steam from the boiler is connected to the condensing chamber (F) as shown by pipe nipple (C), and thus keep this chamber full of water and at boiler pressure. As the steam condenses and forms water it can flow down through a pipe to the bottom of the oil reservoir and being heavier than the oil, it always keeps the oil in the top of the oil reservoir (A). Steam from the condenser also passes down through the equalizing tubes (P), to the top arms over the sight feed glasses, the latter being filled with water up to that point. The water pressure under the oil forces it out through the feed valves (L) and (E) and rises drop by drop through the water in the feed glasses. At the top feed glass connection it is caught by a jet of steam from the equalizing tubes (as previously explained) and passes out with this steam through the oil pipes (W) (only one shown) to the steam chests, air pump or other steam part to be lubricated. There being nearly boiler pressure in these parts, the lubricator pressures are nearly balanced. Pipes extend from the feed valves up into the top of the oil reservoir so that oil will feed until the reservoir is empty. On the side of the oil cup is the "main" lubricator glass (not shown in the illustration) which indicates the amount of oil in the lubricator in the same way that the water glass shows the water in the boiler. In the illustration (Z) is the filling plug and (G) the drain cock. With high pressure boilers a choke is usually put in the oil pipe near the steam chest, as shown in the engraving.

In the style of lubricator shown above the by-pass valves for auxiliary oiling take the place of the old style hand oilers, and in addition to being much more convenient to operate, they enable the rate

SIGHT FEED GLASS AND CONNECTIONS.

of feed to be graded as closely as when the oil is fed through glass. They also do away with the use of the oil can, and prevent the waste and spilling of oil so common when the hand oilers are used.

Each sight feed glass is protected by an automatic check valve above it, and the gauge glass has automatic check valves both above and below it. In case of the accidental breakage of the glass, these valves close instantly, thus preventing the escape of steam and oil to injure those in the cab. The check valves above the sight feed glasses also prevent the current of steam passing through the equalizing pipes from entering the sight feed chamber. Where the glasses are not so protected, this current enters the sight feed chamber, and by its eddying motion acts as a sand blast and cuts away the upper portion of the glass, so that they break very frequently.

Question 193—If a lubricator feeds oil to the cylinders much faster with the throttle closed than open, what is the cause?

Answer—There is always this tendency as there is then no steam-chest pressure, but if the difference in feed is marked, it indicates that the choke plugs are worn too large and new ones should be put in.

Question 194—If there is any drop or "pocket" in the oil pipes leading to the steam chest, will lubrication take place while working steam?

Answer—Practically none, and you will have to shut off and drop the lever a few notches to lubricate the cylinders.

Question 195—In such an event would there be visible feed through the sight feed glasses?

Answer—Yes; but the oil would remain in the bend or pocket of the oil pipes until you shut off.

Question 196—How large should the hole in a choke plug be?

Answer—About the size of an ordinary pin.

Question 197—Will a cold draft of air against the lubricator have any effect upon its proper operation?

Answer—Yes; it chills the oil and water and causes an irregular feed.

Question 198—What would be the effect of filling the lubricator full of cold oil?

Answer—When steam is turned on it will expand the oil and burst or bulge the lubricator or some of its parts.

Question 199—If the sight feeds become stopped up how would you clean them?

Answer—If you cannot blow them out, remove the feed valves (L) and (E) (ilustration above) and run a straw or fine wire through the nozzle.

Question 200—How can the hole in the choke plugs be cleaned out?

Answer—Remove the oil feed pipes and clean with a fine wire or a small brass pin. Do not use a needle or straw as either is likely to break off in the holes.

Question 201—If the equalizing tubes get stopped up, what would be the effect upon the working of the lubricator?

Answer—It would reduce the feed or stop it entirely, especially while working steam.

Question 202—To stop the feeding of a lubricator, which is the surest way, to shut off the water valve or the feeds?

Answer—The feeds, as the water valve may leak.

Question 203—When an engine is left at terminals why is it the surest way to save oil by draining the lubricator?

Answer—When the steam in the boiler condenses to water after all pressure is gone, the partial vacuum may draw the oil from the lubricator should the water valve not be perfectly tight.

TRIPLE FEED LUBRICATOR.

Question 204—After filling a lubricator, what valve should you open first?

Answer—The steam valve first, then the back valve admitting water to the bottom of the oil reservoir. After sufficient steam has condensed to fill the lubricator and sight feed glasses, it is ready to start to work by opening the feeds.

Question 205—If a lubricator fails to work, how may the cylinders be oiled?

Answer—Shut off the engine and drop the lever a few notches and oil through the auxiliary oilers if the lubricator has these attachments, if not, oil through a plug on the top of the steam chests. As previously explained, some modern lubricators permit of graduated feed through auxiliaries with throttle open.

Question 206—Is there much difference between anthracite (or hard) and bituminous (or soft) coal?

Answer—Yes. Hard coal might be called natural coke and burns more slowly and with little or no flame and smoke. On account of its burning more slowly and the customary use of small sizes, anthracite burning locomotives have larger grate area than soft coal burners.

CHOKES (TO INSURE CONTINUOUS FEED TO STEAM CHESTS.)

Question 207—In getting ready to start what is necessary with a hard coal burner?

Answer—Be sure the fire has been well cleaned and see that there are no dead spots. Hard coal will not ignite as readily as soft coal and hence the dead spot must be bared and live fire pulled onto the spot replacing the dead coals on top. It is absolutely necessary to have a good fire before starting out on the road.

Question 208—How should the fire be at leaving time?

Answer—There should be a good bed of fire over the entire grate area and about four inches deep except along the sides, back and corners where it should be twice as deep.

Question 209—Should any coal be put in while starting the train?

Answer—No, it should not. With an anthracite burning locomotive all coal to make the start must be thoroughly ignited before starting, even if it is necessary to use the blower to to get it in that condition.

Question 210—How can you prevent tearing the fire in starting?

Answer—By leaving the door on the latch when the engine is being worked full stroke to start.

Qustion 211—How should hard coal be fired while running?

Answer—By watching for the white heat spots and covering them with fresh coal so that the latter will be thoroughly ignited before that beneath it burns out.

Question 212—Are small or large sizes of coal the hardest to fire?

Answer—Small sizes because the first must be kept thinner to admit the proper amount of air and hence if not watched and replenished will go out in spots the more quickly.

Question 213—About how many shovelfuls of hard coal should be put on a fire at one time?

Answer—Not more than two or three and each scattered as much as possible and not put in one place.

Question 214—If holes are torn in the fire, what must be done?

Answer—Use a hoe or poker to fill them with live coal from another part of the fire.

Question 215—In making stops how can popping be avoided?

Answer—By putting in a fire about the time the engine is shut off. This will serve to cool down the fire at first and later to start the train away from the station.

Question 216—In drifting down grades, what should be done?

Answer—Keep the fire only sufficiently hot to supply the injector, if working, and keep up a uniform boiler pressure. Should the fire be too hot, cover the sides, next the back, and finally the middle portion with green coal but leave bright fire enough next the flue sheet to keep the cold air from injuring the flues. Close the dampers and the open the fire-box door if necessary.

Question 217—After a long wait at a station or siding, is it practical to start without first preparing the fire?

Answer—No it is not, and if tried will generally result in low steam, delays and leaky boilers.*

Question 218—How can the fire be cleaned?

Answer—By pulling back the grate bars one at a time and cleaning the fire through these longitudinal openings which are only 4 or 5 inches wide. It is wise to have a good bed of burning coal before starting to clean the fire so as to be able to rake it over the whole grate after you have done.

Question 219—With anthracite coal what result follows too heavy firing and too heavy a fire before starting?

Answer—The result is what is termed a "rotten" fire, that is, the coal dies out before it is burned and the engine will not steam well until the fire is cleaned.

Question 220—Why is it necessary for a fireman to look ahead and anticipate the work of the engine with anthracite to a greater extent than with soft coal?

Answer—Because it takes so much longer to build up a bright fire.

*The author believes that some hard coal experiences would be good training for such enginemen as start out of sidings with soft coal locomotives without giving the fireman a moment's notice.

Question 221—How is the boiler of a locomotive connected to the frames?

Answer—The front end of the boiler and the frames are securely fastened to the cylinder saddles, again about midway back the boiler is secured to the frames by belly braces to prevent side motion but not expansion, and at the fire-box side motion is also prevented. The fire-box end of the boiler is carried on the frames by expansion plates or by expansion hangers as the case may be, but is free to move backward and forward on the frame as expansion and contraction take place. If the frames were as hot under steam pressure as is the boiler, the fire-box end of the boiler could be rigidly attached to the frames.

Question 222—With an ordinary sized locomotive boiler how much will the fire box move on the frames?

Answer—About three-eights to one-half of an inch.

Question 223—Are the cylinders fastened rigidly to the frames?

Answer—Yes, in fact they are generally a part of the saddle castings.

Question 224—Are the driving wheel axles secured rigidly to the frames?

Answer—No; the driving boxes riding these axles can move up and down to permit the wheels to conform to the inequalities of the track, but are rigidly held against forward and back motion by shoes and wedges bearing against the jaws of the frames.

Question 225—Is the frame supported directly by the driving boxes?

Answer—No. The driving boxes support springs, the ends of which are fastened to the frame directly or through equalizers.

Question 226—What is the purpose of the equalizers?

Answer—To always retain the same weight upon each driving box even when one wheel strikes a high or low spot in the track. They also make an engine ride more easily on rough track.

Question 227—What are the principal duties of an engineman before taking a locomotive from the engine house?

Answer—To compare his watch with standard clock, examine the bulletin board and engine work-report book to see what work was reported and what done on the engine, and look the engine over carefully. To see that there is water enough in the boiler and that water glass, gauge cocks and both injectors are in working order. To know that all necessary tools

and supplies are on the engine and see that the fireman has properly attended to his duties. Try the air brakes and steam heat.

Question 228—What tools and supplies are necessary?

Answer—The requirements are different on different railroads and a list of the tools and supplies expected on an engine are usually published in some form. An engineman's experience soon teaches him to be particular in this regard and to ascertain that there are extra globes, chimneys, blocking for breakdowns, as well as oil, signals, lamps, tools, etc., usually prescribed. A few bolts and nuts are often of great advantage.

Question 229—What care should be taken if brasses have been filed, valves faced, piston packed, etc.?

Answer—Examine them carefully, note that all parts are tightened up and well lubricated.

Question 230—How should you start a train?

Answer—Always ring the bell before starting. With the lever in the corner, open the throttle slowly, taking up all slack before working steam hard. Look back and see that switches are closed, that the entire train is coupled and that no stop signal is being given.

Question 231—After starting, how should the locomotive be worked to obtain the most economical results?

Answer—As a general rule with full throttle and as short a cut-off as required to do the work. Should the work be very light, it is generally conceded that instead of hooking the lever back of a six-inch cut-off, it should be left in that notch and the throttle eased off. The engine will ride better thus and lessen the liability of pounding flat spots in the tires besides causing less cylinder condensation.

Question 232—In case you broke down on the road what would you do?

Answer—Stop at once, protect the train, and examine to ascertain the damage. If not possible to repair at once or without delay to other trains, endeavor to repair sufficiently to pull the train to the next siding, then report to the proper officials.

Question 233—What work about an engine should you attend to or inspect before going into service?

Answer—See that all nuts are tight and locked or keyed on, that wedges are set up, rods keyed up and secure, engine boxes well packed, headlight clean, all oil holes open and bearings well lubricated.

Question 234—How hot should you have engine oil to oil around with in winter?

Answer—No hotter than blood-heat—98°—and if oil is then too thick to run well, thin it down with kerosene.

Question 235—What is the harm of thinning it by heating it very hot?

Answer—As soon as it strikes the cold surfaces it will thicken and not feed properly to the bearings.

Question 236—How would you set up wedges?

Answer—Block the tank wheels well and place the pins on one side on the upper back eighth, reverse the engine a few times with the throttle open, finally leaving the lever in the forward motion as that will pull the boxes away from the wedges. Then beginning at the main driving wheel, set the wedges up tight and pull them down a turn. With the engine cold, set up each wedge until it "sticks" when two men with bars "jump" the wheel, then pull it down a trifle until it loosens. Many advise this latter method under all possible circumstances.

Question 237—When wedge-bolts are broken so that you have to slip in an extra nut between the wedge and the binder, or splice the bolt by running half of the nut on each piece, should the wedge be set up tight?

Answer—It should be left down a trifle for it is better to have the box pound a little than to run the risk of having the wedge stick on the box and get pulled up and stick fast with no means of pulling it down.

Question 238—What trouble is likely with wedge bolts broken?

Answer—Wedge is likely to stick to box on rough track and be pulled up so high as to stick and cause the box to run hot.

Question 239—What is usually meant by cylinder packing?

Answer—The rings that surround the piston proper (not the piston rod) and make the joint on the walls of the cylinder thereby preventing steam from passing by the piston.

Question 240—What is meant by piston packing as ordinarily applied in locomotive terms?

Answer—The piston rod packing, that is, the packing that forms the slip joint between the piston rod and the gland on the back cylinder head.

Question 241—What would be the effect of broken cylinder packing?

PISTON PACKING RINGS AND VIBRATING CUP.

Answer—Steam when admitted to one end of the cylinder would blow by the piston and show at the other end of the cylinder if the cylinder cocks are opened.

Question 242—What is meant by "snap ring" packing?

Answer—A round ring usually of cast iron, and cut at one point. This ring is opened up and snapped over a solid piston or applied each side of the bull-ring in a made up piston. Such rings are made from one-eighth to one-fourth of an inch larger outside diameter than the cylinder and a piece cut out so that the ends will just touch when compressed in the cylinder.

Question 243—When such rings are first applied to a cylinder why do they often permit steam to blow by for a short time?

Answer—Because they generally have to wear slightly before they conform perfectly to the shape of the cylinder.

Question 244—If a ring becomes worn until it has a smaller outside diameter than that of the cylinder what will be the result?

Answer—It will allow steam to blow by the piston, but not always at high steam pressures. The engine will be wasteful of steam and yet if tried under high steam pressure may set the packing out sufficiently to prevent a blow. With such an engine under short cut-off, when the steam had expanded somewhat in the cylinder the pressure would not hold the packing rings in place and steam would blow by. Test such an engine under low steam pressure.

Question 245—What would be the "symptoms" in the above case?

Answer—The engine may have made several thousand miles since shopping and used steam economically and then lose her snap and apparently blow through at early cut-off and high speed. By dropping the lever, thus increasing the pressure behind the snap rings during the entire stroke, the blow ceases.

Question 246—Is it a part of your duties as an engineman to see that you have full supplies before attaching your engine to a train?

Answer—Ascertain that the fireman has attended to his duties and drawn all necessary supplies, see that proper tools and blocking are on the engine. It must be remembered that the engineman is primarily responsible for the work of his fireman and hence should know as to coal, water, sand and oil being on the engine, that the flues and fire-box are not leaking, the fire in proper condition and the ash pan clean, etc.

Question 247—Should particular attention be given to an engine where brasses have been filed, valves faced, wedges set up, etc.?

Answer—It should and such parts receive extra lubrication until known to be running cool.

Question 248—What will be the result if brasses are not kept keyed up properly?

Answer—They will wear rapidly and often break themselves. Any serious pound about a locomotive is liable to loosen various parts of the engine.

NEEDLE FEED OIL CUP.

Qusetion 249—How would you key up a main rod?

Answer—Place the engine on the lower quarter on that side to key up the forward end, and on the upper forward eighth to key up the back end of the main rod.

Question 250—Why are these positions chosen?

Answer—Both the cross-head pin and the main pin wear somewhat out of round from service, and experience teaches that their largest diameter is lengthwise of the rod at these points.

Question 251—Is it safe to key up side rods with the wedges down or loose?

Answer—It is not, the wedges should first be set up or you are likely to key the rods out or tram.

Question 252—Would you set up wedges as tight on a passenger engine as on a freight engine?

Answer—No. On a passenger engine most men prefer to set them up a little at a time.

Question 253—Would the condition of the track make any difference?

Answer—Yes, on rough track wedges are more likely to stick if set up tight.

Question 254—When wedges are set up properly how would you proceed to key up the side rods?

Answer—Place the engine on the center and loosen all keys on that side, key the main connection first and then work in both directions from it. Repeat this operation for the other side of the engine.

Question 255—What would be likely should you key up the side rods in any other position than on the center?

Answer—You are likely to throw the engine out of tram.

Question 256—What is meant by an engine being out of tram?

Answer—It means either (1) that the driving wheel centers are not the same distance apart on both sides of the locomotive, (2) that the side rods are not the same length center to center as the driving wheels, (3) that an axle is sprung or (4) that a pin is sprung or out of quarter.

Question 257—What will be the result if an engine is out of tram?

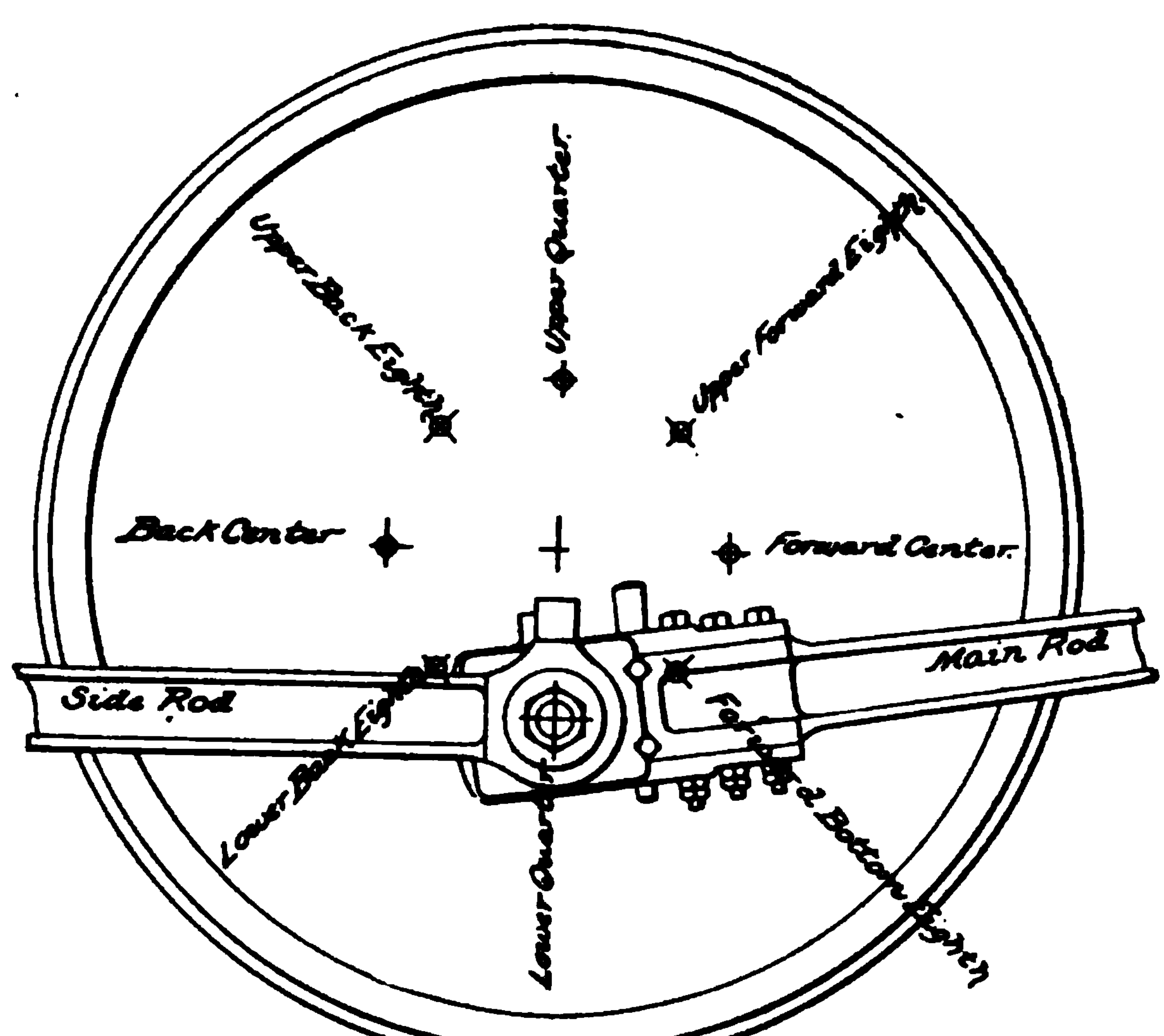
Answer—She will ride hard, having a hitch every time the rods pass the center, the pins are likely to heat and considerable of the engine's power be wasted.

Question 258—If you felt a pound after keying up a main rod what is likely the cause?

Answer—Probably the main rod is too long and allows the piston to strike the front cylinder head. Such a pound is most noticeable when steam is shut off and the engine drifting as there is then less compression to counteract this.

Question 259—How could you shorten a main rod?

Answer—By changing a thin liner from the end of the rod to the back of the strap. Such work is usually done at roundhouses by the machinists and repairmen.



POSITION OF CRANK PIN.

Question 260—How would you locate a pound in an engine.

Answer—Put the engine on the top quarter on the one side to be first tested and have the fireman or some one competent apply the brakes, open the throttle and reverse the engine several times. I would be on the ground and carefully watch all boxes and rods and thus ascertain where the pound was. Repeating this procedure for the other side.

Question 261—Will a loose pedestal brace or bolt cause an engine to pound?

Answer—It will and if not attended to is likely to break the frame.

Question 262—With a follower bolt loose what will be the effect?

Answer—It will cause a pound at the forward end of the stroke when it strikes the front cylinder head. Shutting off steam, as in the case of too long a main rod, will increase the pound.

Question 263—Is it safe to run with a loose follower bolt?

Answer—It is not, as it is likely to come out, knock out the front cylinder head and perhaps break the piston and cylinder. Work a little steam and try to get to the next siding if the pound does not increase, and there take off the cylinder head and remove the bolt unless you have a good wrench with which to tighten it.

Question 264—What would you do with a badly leaking or burst flue?

Answer—Plug it tightly with an iron plug, using a flue plugging bar provided for that purpose and drive it in solid.

Question 265—Why is a leaky front end injurious to a locomotive?

Answer—Because it allows air to enter, impairing the draft through the fire also causing cinders to burn and warp the front end, thus producing still further trouble.

Question 266—Why is it necessary to keep the cinder hopper valve and all joints in the front end tight?

Answer—To keep air out of the extension front end.

Question 267—Why are some roads building locomotives without cinder hoppers and "peep holes" in front ends?

Answer—To prevent leaking of air and consequent warping and burning of plates and front door. Such engines are arranged inside to automatically break up and throw out all cinders through the stack. They have what is termed a "self-cleaning" draft arrangement.

Question 268—If for any reason you should have occasion to open the front end door, how would you proceed to tighten up clamps?

Answer—Close the door, tighten the bottom clamp first, then the clamps on either side; the top one last, so that if the door or ring is warped any leakage will be at the top of door and though injurious in a degree to the draft of the engine, still it will not cause the cinders in front end to burn.

Question 269—What should be examined or reported for examination in case an engine sets fires?

Answer—The netting in the front end (or stack, if diamond stack) and the ash pan. There should be no holes in either and in timber countries many roads use netting under the ash pan dampers.

Question 270—If an engine was known to be setting fires on the road, how would you handle it to get to terminal for repairs?

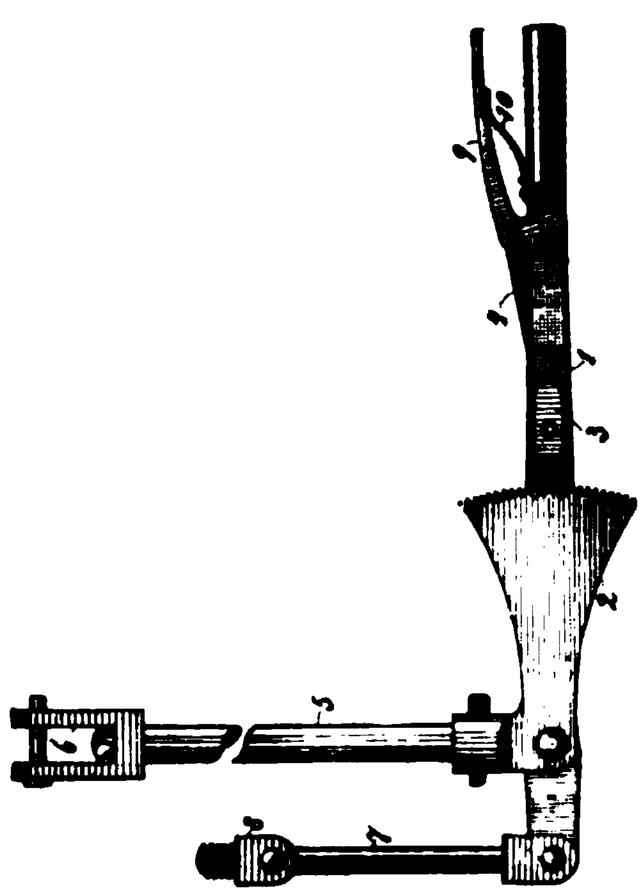
Answer—Work the engine as lightly as possible and avoid all slipping.

Question 271—What requirements have some roads as to passing over wooden bridges and long trestles?

Answer—That the dampers must be closed. All roads order positively that grates must not be shaken in such places.

Question 272—If grates broke or burnt out while on the road, what would you do?

Answer—If they are down at one end only, pry them up in place and block with iron water pail, brick, or anything available. Clean all fires out of ash pan. Track straps, fish-plates, or the like may often be used in place of a broken grate. It is a difficult matter to run far with poor coal when unable to shake grates or remove clinkers when formed.



THROTTLE LEVER AND STEM.

Question 273—What would you do with an engine in your charge, if the throttle should become disconnected?

Answer—If disconnected open, I would be unable to shut off steam, and it might be very difficult to manage the engine with the reverse lever and brakes; hence I would reduce the boiler pressure sufficiently to handle the reverse lever readily, notify the train crew to be prepared to assist with brakes and reduce part of the train if necessary.

Question 274—Suppose it was disconnected closed?

Answer—I would have no way of getting steam to the cylinders and on a busy line would get engine in shape to be towed in, disconnecting if any considerable distance to run.

Question 275—With lubricator working would it be necessary to disconnect?

Answer—Most generally, yes. The oil pipes would not supply steam enough to lubricate the cylinders although the valves might possibly be lubricated.

STEAM DOME, STAND PIPE, THROTTLE VALVE AND CONNECTIONS.

Question 276—How is the throttle valve (13) opened?

Answer—By opening the throttle lever latch (3), pulling back the throttle lever (1), thereby pulling out the throttle rods or stem (5). A forked end (6) of this stem is pinned to one arm of the bell crank (12) the other arm of which is connected to the throttle valve (13).

Question 277—How is steam admitted to the cylinders?

Answer—The bell crank (12) is attached to the stand pipe in the steam dome from the top of which steam is admitted through the throttle valve, stand pipe and dry pipe (running the length of boiler, as shown in full view of the Locomotive elsewhere.) The front end of the dry pipe is connected just forward of the front flue sheet to the "nigger head" or Tee pipe each arm of which joins the two steam pipes in the

extension front end. The latter pipes are bolted to flanges of the saddle directly over the steam passages which lead to the steam chests. From thence the steam is distributed to and from the cylinders by the slide (or piston) valves.

Question 278—What, then, is wrong when the throttle becomes disconnected and what could you do if on a branch line a long distance from the shops?

Answer—One of the pins has probably come out of or broken from the bell crank (12) or the stem (5) or throttle valve rod (11) is broken. Blow all steam off the boiler, take up dome cap, discover the defects, send it in for repairs or better still fix it yourself at the nearest blacksmith shop. In early days of railroads in this country, enginemen frequently did such extensive repairs as this themselves.

CYLINDER, VALVE, STEAM CHEST AND PARTS.

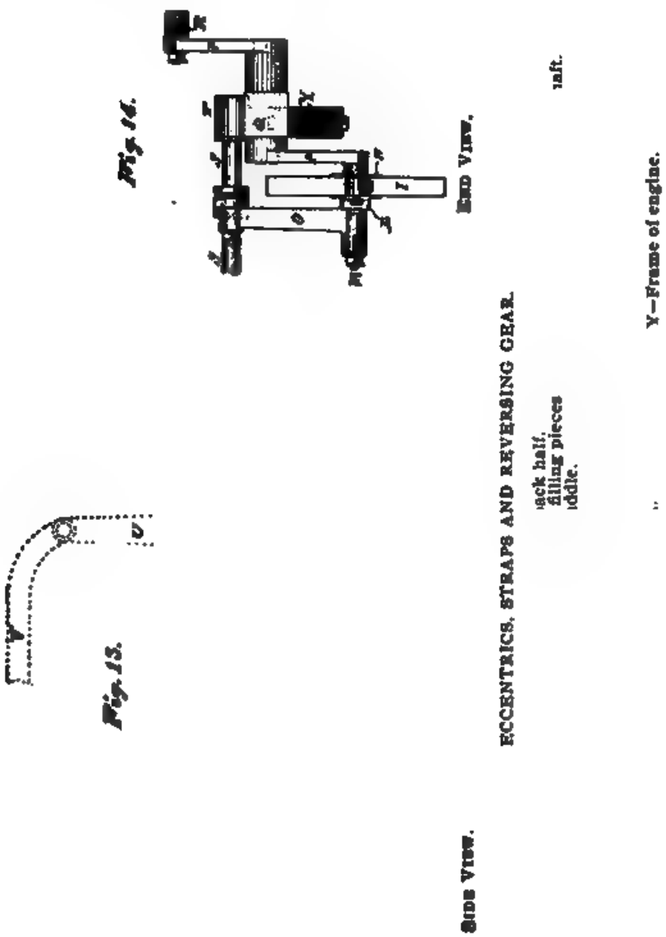
a—Front cylinder port.
b—Back cylinder port.
c—Exhaust port.
C—Cylinder.
d—Slide valve exhaust cavity.
e, f, g, h—Bridges between ports.
j—Valve stem.
k—Front cylinder head.
m—Piston rod packing in gland.
n—Valve stem packing in gland.
p—Piston rod.
P—Piston (with packing rings.)
s—Back cylinder head.
S—Steam chest
V—Valve with balance strips.
y—Steam port.

Question 279—Should the exhaust get out of square what does it denote?

Answer—That there is something wrong with the valves or valve motion.

Question 280—Name the various causes.

Answer—Slipped eccentric, loose bolts in straps or blades, sprung tumbling shaft, bent rocker arm, broken valve yoke, broken valve or valve seat, or one valve dry.



Question 281—What would you proceed to do to discover the trouble?

Answer—After I shut off I would feel the lever carefully to note if the valves seemed dry or if there was anything pulling like a hot eccentric. When stopped examine each eccentric, its strap and blade bolts and see if tight and in place. Note if anything appears loose about the tumbling shaft, rocker arm boxes, or valve stems.

Question 282—With one eccentric slipped or one strap or blade loose would an engine be lame under all points of working?

Answer—No. If it is a go-ahead eccentric, the engine would not be lame when tried at full stroke backing up.

Question 283—What would be the difference with valve, valve seat, or rocker arm sprung or broken?

Answer—The engine would be lame in both directions—going ahead and backing up.

Question 284—With large valves and long eccentric blades what is well to remember?

Answer—That lameness is most often caused by lack of oil to one valve. Shut off and drop the lever down increasing the feed on that side of the lubricator, or better still, go out on the steam chest and allow a small quantity of graphite and water be drawn in through the relief valve.

Question 285—How would you inspect for slipped valve motion?

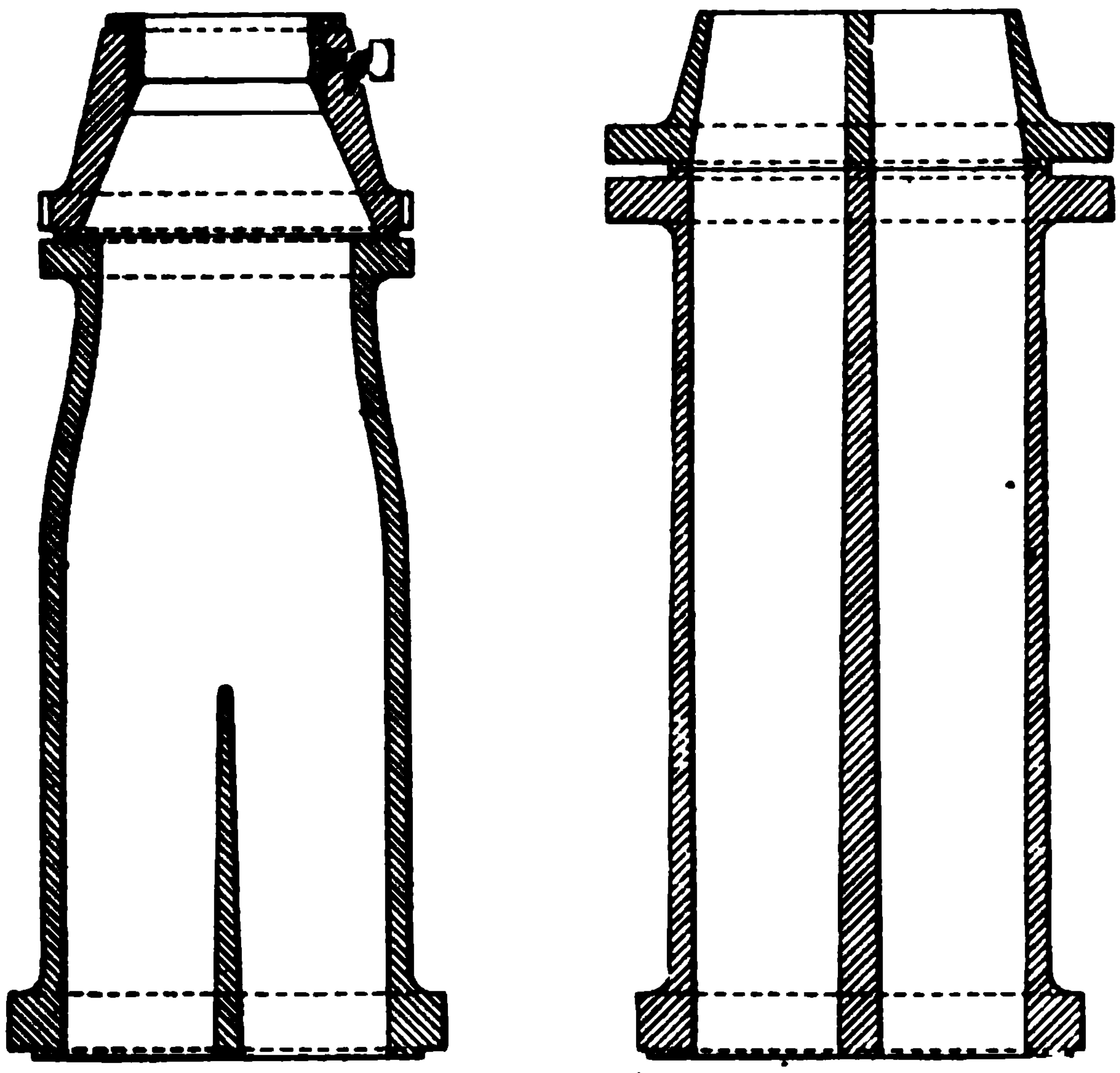
Answer—Examine the bolts holding the eccentric straps together and the blade bolts. See that the eccentric cams are in the proper place on the axle, and if rocker boxes, valve rods or stems are loose. If you are unable to find anything wrong, test for broken valve, valve-seat, broken or sprung yoke as explained in answer to question 283.

Question 286—Will any defects in the front end cause an engine to sound out of square?

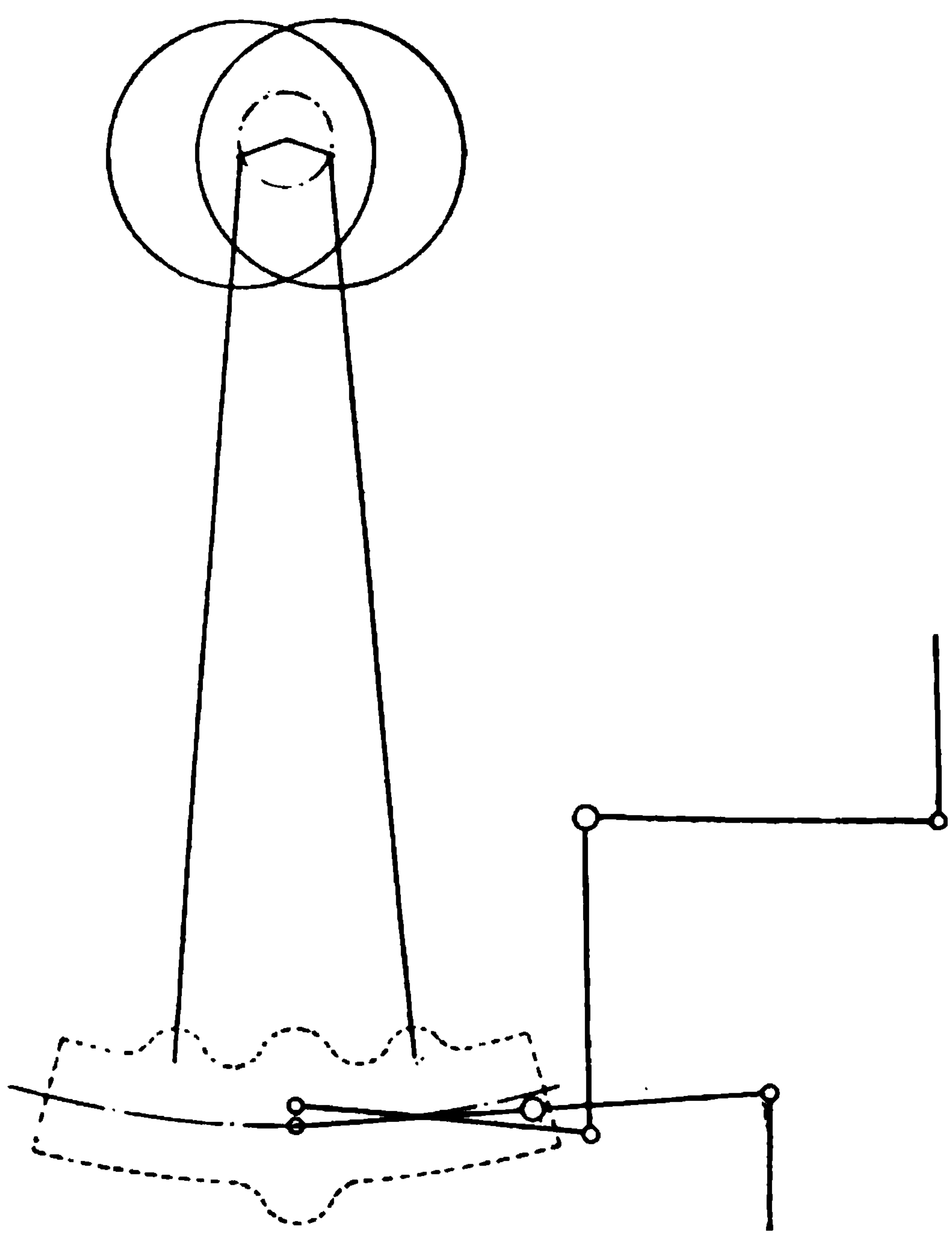
Answer—Yes. Exhaust pipe joint blown out on one side or one tip of a double nozzle blown out. Sometimes a worn out petticoat pipe will cause this.

Question 287—What positions do the eccentrics occupy with reference to the crank pin on the same side of the engines?

Answer—With indirect valve motion (that is, where the rocker arms reverse the motion of the link block in transmitting it to the valve rod) and the ordinary valve with outside admission, the eccentrics *follow* the pin by one-quarter or 90 degrees less the amount of lead and lap. With direct motion they *lead* the valves at right angles less the amount of lead and lap. Where the valves have inside admissions the eccentrics stand exactly opposite or 180 degrees from the above positions.



SINGLE AND DOUBLE EXHAUST PIPES AND NOZZLES.



INDIRECT VALVE MOTION, WITH ROCKER ARM.

Question 288—What is meant by direct valve motion?

Answer—Where both ends of the rocker arms are either above or below the frame and pointing in the same direction, that is, the link blocks and valve rods travel in the same direction at the same time.

Question 289.—What is the effect of a slipped eccentric?

Answer—Either to increase or diminish the lead.

Question 290—What is meant by the "lead" of a valve?

Answer—The width of the steam port opening when the engine is on center (on that side) is termed the lead.

Question 291—What term is used where an engine has no lead?

Answer—The engine is called "blind."

Question 292—By moving an engine slowly, how can you tell which eccentric has slipped?

Answer—Have the fireman place the lever in full motion which ever way you are moving, open the cylinder cocks and you observe carefully if steam is admitted into each end of the cylinder just before the engine is on centers.

Question 293—What will be the effect if the eccentric has slipped *toward* the crank pin on that side?

Answer—The amount of lead will be increased and hence steam admitted to the cylinder considerably before the piston gets to the end of its stroke.

Question 294—What will be the effect if the eccentric has slipped *away from* the crank pin on that side?

Answer—The lead will be taken away, and if slipped much, the piston may have started on its return stroke before steam is admitted.

Question 295—How can you tell which is the go-ahead and which is the back-up eccentric?

Answer—The go-ahead eccentric is attached to the top of the link, the back-up to the bottom, on all ordinary locomotives.

Question 296—What other aid have you to find a slipped eccentric or rod after you have stopped?

Answer—If I found one eccentric hot or set screws loose, would consider that first.

Question 297—If only one eccentric has slipped, how can you tell what its position should be in reference to the other eccentrics?

Answer—The go-ahead eccentric on one side should be exactly 90 degrees or at right angles to the other go-ahead eccentric,

and the relative positions of the back-up eccentric are the same. Which ever crank pin of the engine leads, the eccentric on that side leads the opposite one. This answer is true for all kinds of valve motion.

Question 298—How can you set an eccentric on the road by means other than its relative position to the others, or to the crank pin?

Answer—Place the engine on either center on the defective side. Put the lever in full gear for the good eccentric and with a knife mark the valve stem close to the gland. Now place the lever in equally full gear (gauging by the link block) in the opposite direction and then move the loose eccentric around on the shaft until the scratch on the valve stem comes even with the gland again. Another way is to put the engine on the center on that side, put the reverse lever in full gear for that motion, set the brake and block wheels securely; have the fireman open the throttle slightly while you move the slipped eccentric in the opposite direction from the one next to it until steam shows at the cylinder cock at the end of the cylinder wherein the piston lies.

Question 299—Why are slipped eccentrics of less occurrence now than in former years?

Answer—Now they are most all keyed on, the set screw only keeping them from slipping endwise on the axle; formerly the set screw was depended upon entirely to hold them in place.

Question 300—On which center would you place an engine to set an eccentric?

Answer—On which ever center enabled me the more easily to get at the eccentric and set screw.

Question 301—What is meant by outside "lap" of a valve and what is "lap" for?

Answer—Lap is the distance the edges of a valve project beyond the ports when the valve is in the center of its seat. By the use of lap the steam is held in the cylinder and allowed to expand while the valve is traveling the amount of its lap.

Question 302.—In case of a very hot eccentric, would you put water on it?

Answer—You should not, as it would be likely to break or warp the straps.

Question 303—What usually causes the eccentrics or blades to slip?

Answer—It may be any of several causes: Set screws loose, hot eccentrics, or some one tightening up set screws when the bolts holding the two eccentric parts together are loose. In this latter case the cam would be jacked out tight against the straps.

Question 304—What would you do for a hot eccentric on the road?

Answer—Oil it well, using valve oil if very hot; see that the strap was not tight on the cam and if it were, loosen the strap bolts and put in one or more tin liners between the two halves of the strap on both sides, then tighten bolts.

Question 305—How do some roads secure blades in straps so as to prevent their slipping?

Answer—Some roads slot all holes and after the blades are set and adjusted, they run soft metal into the slots beside each bolt. Other roads often slot one hole in each blade and after setting valves drill the remaining holes to correspond with those in the strap without slotting them.

Question 306—What would you do to "disconnect" an engine on one side as the term is generally applied?

Answer—Place the valve in the center to cover the steam ports and clamp or bind the stem to hold it there, take down the main rod and block the cross head securely (preferably at the back end of stroke). If any side rods are broken, remove the same ones on the opposite side.

Question 307—On very heavy locomotives is there any way to avoid taking down the main rod?

Answer—Yes. If but a short distance to go, block the valve just enough ahead of the center to admit a little steam to the back end of cylinder, and if the engine does not have by-pass valves take out the back cylinder cock or block it open and loosen the front cylinder head.

Question 308—For what causes would you disconnect as stated?

Answer—For broken front cylinder head; valve, valve seat, valve stem or rod broken; broken rocker arm, eccentric, strap, blade, link or parts of link.

Question 309—If you take down one eccentric blade what should you do to prevent the link turning over, binding, or striking the engine truck frame?

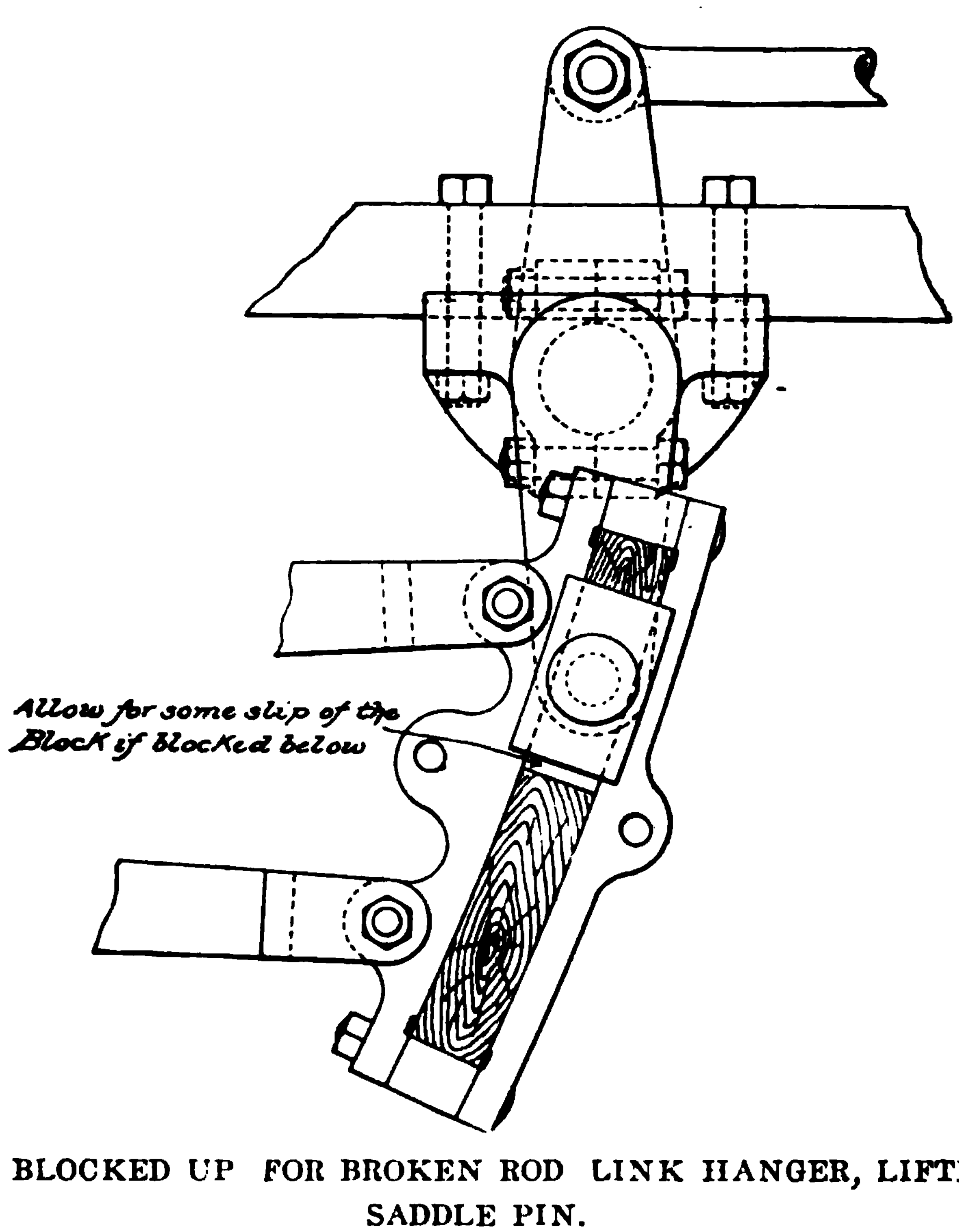
Answer—Tie the top of the link to the hanger or otherwise fasten it but not too tightly. It is generally best to take off both eccentrics and straps on that side if you have to take down one.

Question 310—Can an engine be run ahead with a back up eccentric strap or blade taken down?

Answer—Yes. For if kept in full gear the link block will get all its motion from the go-ahead blade. The reverse condition is true with regard to a broken go-ahead eccentric. This practice should not be followed except in moving an engine to nearest the siding before disconnecting the valve stem.

Question 311—What can be done if the reverse lever, reach rod, lifting shaft or link hanger is broken?

Answer—Block the links up with a piece of wood to the desired point of cut off, but do not try to reverse the engine without first placing the block at the other end of the link.



LINK BLOCKED UP FOR BROKEN ROD LINK HANGER, LIFTER OR SADDLE PIN.

Question 312—What would you do if the whistle or pop valve should blow out?

Answer—Plug the opening with a piece of soft wood and tie it down if possible.

Question 313—How is it possible to fill the boiler from the tank without steam pressure?

Answer—By towing the dead engine with another engine. To fill the boiler of the dead engine, close the cylinder cocks, relief valves, etc.; open the injector throttles, tank valves, and leave the lever in full gear for the direction going. The pistons by their pumping action will form a partial vacuum in the boiler which will be supplied by water from the tender.

Question 314—If stuck in a snow bank, how would you keep water in the tank?

Answer—If necessary, shovel snow in the tank and melt it with the heater.

Question 315—When an engine is standing and throttle is closed, what will cause steam to escape from the cylinder cocks?

Answer—If the lubricator was shut off so that no steam could come through the oil pipes, it would indicate either a leaky throttle or a leaky dry pipe.

Question 316—How can you distinguish a leaky dry pipe from a leaky throttle valve?

Answer—With a dry pipe leaking, if there is enough water in the boiler to cover it, the escape from the cylinder cocks will be nearly all water. With throttle leaking it will show dry steam.

Question 317—Is a leaky throttle dangerous?

Answer—It is, and should be reported and ground in as soon as possible, in the mean time leave the cylinder cocks open when standing and block the wheels well before going under the engine or leaving her.

Question 318—What is the position of the dry pipe in a locomotive boiler?

Answer—Up near the shell of the boiler as shown by the illustration of the 8-wheel locomotive found elsewhere in this volume.

Question 319—Then to test for leaky dry pipe should there be more water than usual in the boiler?

Answer—Yes. Some boilers have to be filled above the top of the water glass in order to entirely submerge the dry pipe should the latter leak at its top side.

Question 320—Name the various causes for an engine pounding.

Answer—Loose or worn rod brasses or worn pins; loose or worn wedges or binders; driving box brasses worn or loose in the boxes; piston rod loose in its crosshead; worn guides or crosshead; loose gibs in crosshead; loose cylinders or deck; flat driving wheels; main rod too short or too long or loose

follower bolts; badly worn expansion pads on the sides of fire box; a broken frame; pedestal bolts loose.

Question 321—Name the various causes for a blow in an engine?

Answer—Valves, valve seats or cylinder cut; balance strips broken, struck down or broken springs under strips; balance plates too high above the valve; broken or worn packing rings in piston valves; broken or worn cylinder packing rings or rings turned around so that their openings come opposite each other at the top of piston; broken valves or valve seats and some times a blow under a false valve seat.

Question 322.—How would you test for a blow in the balance strips or valves?

Answer—Place the engine on the center (top preferred), reverse lever in center notch and open throttle and cylinder cocks. If very little steam shows at either cylinder cock on that side, defective balance strips would still cause a blow through the hole in top of valve to the exhaust cavity and out of the stack. By moving the lever a notch or two each side of center, just enough to connect the exhaust cavity with either cylinder port, a slight escape of steam will appear at the corresponding cylinder cock. Test the opposite side of the engine in the same way.

Question 323—What is meant by a balanced valve?

Answer—It is a valve having part of its top surface relieved of steam chest pressure.

Question 324—What are the most ordinary types of balanced valves?

Answer—The Richardson balance with rectangular balanced area enclosed between four strips; the American balance with circular bevel spring rings (one or two); and the piston valve.

Question 325—With the two first named balancing of slide valves, what impinges upon the strips or spring rings on top?

Answer—A balance plate which is a smoothly finished plate suspended from the steam chest cover and whose face is parallel with the valve seat.

Question 326—What provision is made for the escape of any steam that may leak to the inside of the balance strips or rings?

Answer—A hole is drilled through the top of the valve into the exhaust cavity as shown in the accompanying illustration.

Question 327—If this hole were plugged, what would be the effect?

Answer.—The valve would be unbalanced and like an ordinary slide valve.

Question 328—Why are all large valves balanced?

Answer—To reduce the frictional resistance and also the wear between valve and their seats.

Question 329—What advantages are claimed for piston valves?

Answer—Greater port areas and more evenly balanced valves.

RICHARDSON BALANCE SIDE VALVE. SHOWING METHOD OF BLOCKING IN STEAM CHEST.

Question 330—In what way have some slide valves been given greater port areas without increasing the size of the valves?

Answer—By supplemental ports. The Allen valve being the most common.

Question 331—Explain the Allen valve.

Answer—The Allen valve has supplemental ports on the face of the valve connected by a passage over the exhaust cavity. When the steam ports are opening the steam is admitted to the cylinder through the supplemental port at the same time as it is by the edge of the valve, thus giving double port opening for rapidly filling the cylinder at the beginning of the piston's stroke. This double port opening is clearly shown by the arrows, in the accompanying illustration.

ALLEN PORTED SLIDE VALVE.
(Showing early admission period.)

Question 332—What is outside lap?

Answer—It is the amount the valve projects over the cylinder port edges when the valve is in the center of its seat. (See graphic illustrations.)

Question 333—What is its purpose?

Answer—To cause the engine to use steam more expansively.

Question 334—What is inside lap?

Answer—The amount the inside edges of the exhaust cavity overlap the nearest edges of the cylinder ports when the valve is in the center of its seat. (See graphic illustration.)

Question 335—What is meant by the valve being "line and line" inside?

Answer—That with the valve on the center of its seat, the inside edges of the cylinder ports are in line with the edges of the exhaust cavity. (See graphic illustration.)

GRAPHIC DEFINITIONS OF VALVE TERMS.

Question 336—What is meant by clearance?

Answer—Clearance is the same as negative inside lap, that is the cylinder ports have a slight opening to the exhaust cavity when the valve is in the center of its seat. (See graphic illustration.)

Question 337—Explain what is meant by working steam expansively.

Answer—Steam is worked expansively by cutting off the supply to the cylinder at any desired point and allowing whatever steam has already entered the cylinder to force the piston for the remainder of its stroke by its expansion.

Question 338—What is the advantage of this?

Answer—To effect an economy of steam which means economy of fuel. The following tables from a well known authority will clearly indicate the reasons for this economy if the student will compare the total heat with the amount of work done in each case:

Cut-off Inches.	Initial Steam Pressure	Ratio of Expansion	Average Cylinder Pressure for Entire Stroke.	Ft.-Lbs. Work Done	Heat Contained in Steam Used.	Pounds of Water Used in doing the work.
8	200	3	125	31,800	618	.52
24	140	1	125	31,800	1299	1.12

EXPLANATION.—The above table shows that 200 pounds of steam with a cut off of 8 inches (1/3 stroke) gives the same average cylinder pressure for the whole stroke and does the same amount of work but with less than one half the heat and water that a full 24 inch stroke with 140 pounds of steam pressure will give.

Pounds of Steam Used.	Initial Steam Pressure.	Cut-off (with 24 inch Stroke.)	Ratio of Expansion.	Pressure in Cylinder at End of Stroke.	Average Cylinder Pressure for Entire Stroke.	Ft.-lbs. Work Done.	Total Heat at 200 lbs. Pressure.	Total Heat at Final Pressure.	Heat Saved.	Comparison of Work Done.
1.57	200	24	1	200	185	47,064	1833	1833	0	1.00
1.57	200	12	2	100	155	78,864	1833	1807	26	1.67
1.57	200	8	3	66	125	95,400	1833	1793	40	2.02
1.57	200	6	4	50	105	106,848	1833	1775	58	2.27

EXPLANATION.—From the above table the last column shows the relative advantage of the shorter cut-offs over the full stroke—the first line of table.

Question 339—Cannot economy be effected with cut-offs still shorter than six inches?

Answer—Not with our modern high pressure boilers, for with still greater expansion the final temperature in the cylinder is so low that great condensation takes place in the cylinders.

Question 340—Is there any other bad result from too short a cut-off?

Answer—Yes. Flat spots are made in driving wheel tires by such practice. Some roads go so far as to block the quadrants of locomotives so that the reverse lever will not latch anywhere between the center and the six-inch cut-off.

Question 341—What effect has it on the valve to lengthen or to shorten the blades?

Answer—It equalizes the travel with reference to the center of the valve seat but it does not alter the total lap or lead of the valve —whatever amount it takes from one end of the valve is added to the other end, that is to say, if the lead is one-sixteenth inch at one end and line and line at the other end, if you lengthen or shorten the eccentric blade (according as the rocker arms are arranged), the lead can be divided so as to be one thirty-second of an inch at each end.

Question 342.—What is the usual cause for cracked or broken steam chests?

Answer—Reversing an engine when the throttle is shut off and the engine is running at high speed.

Question 343—Why is this likely to rupture a steam chest?

Answer—The cylinders of a reversed engine draw air and gases from the front end and force them into the steam chests, steam pipes, dry pipe and stand pipe, and as the throttle is closed there is no escape. The more modern locomotives have steam chest relief valves in order to relieve such excessive pressure.

Question 344—What should be done if an engine is reversed at high speed?

Answer—Open the throttle which will allow the air to pass into the boiler and be relieved at the safety valves.

Question 345.—How would you proceed with a cracked steam chest?

Answer—Drive iron wedges or nails between the studs and the chest so as to crowd the broken parts together and prevent as much breakage as possible. It may be necessary to slack up on the cover while doing this.

Question 346—What would you do with a totally demolished steam chest?

Answer—On a busy line of railroad you should disconnect and be prepared to be towed in. If on an isolated branch a blind gasket could be put in the steam pipe, or more easily place heavy blocking over the steam ports and hold them down with strap iron or a part of the broken cover, placed over the studs and screwed down tight.

Question 347—What would you do with a broken valve stem, gland or stud?

Answer—Brace the gland in place by a piece of board placed against the yoke or the running board bracket or both.

Question 348—If the reverse lever should get caught and bound tightly at a short point of cut off (due to broken driving spring, spring hanger, or equalizer) what would you do?

Answer—Try to pinch the light engine ahead sufficiently to take steam, then block up for broken parts. If necessary to get the train off the main track quickly, you can disconnect the reach rod from the tumbling shaft lever and let the links drop down onto the links blocks so that the engine will be in full forward gear. If you have any distance to go, get the engine blocked up for the broken parts, free the reach rod and re-connect the tumbling shaft arm.

Question 349—What would you do for a broken piston road?

Answer—If the front cylinder head has been knocked out, as usually happens, remove all broken parts and only disconnect the valve stem on that side, clamping the valve in its central position. If the crosshead is not damaged, there is no necessity of taking down the main rod.

Question 350—What would you do for a broken front cylinder head?

Answer—Disconnect the main rod and valve stem, on that side, clamp the valve in the center and securely block the cross-head. If but a short distance to go, remove all broken parts from the cylinder, oil it well, take out back cylinder cock or indicator plug, and proceed without taking down the main rod. The valve stem should always be disconnected and valve clamped on center. (An engine may be able to pull its train a train length off the main line before any disconnecting is done.)

Question 351—What would you do if an engine truck wheel or axle breaks?

Answer—Remove the broken parts and chain the truck frame up to the engine frame. It is also well to chain truck frame to some part of the opposite engine frame in order to keep the good wheel from leaving the rail.

Question 352—What would you do with a broken tender truck wheel or axle?

Answer—Remove the broken parts and chain up the disabled end of the truck by chaining around some part of the tank frame or else to the end of a tie placed over the top of tank.

Question 353—What could be done with a totally demolished tank truck?

Answer—Substitute a car truck or jack up tank and place the good truck under the center of the tank and proceed ahead slowly without train. In such cases a link and pin coupling to a car behind makes it possible to move either ahead or backwards with greater safety.

Question 354—How could an engine be moved if the engine truck was demolished?

Answer—Jack up the front end of engine and block up on top of the forward driving boxes and run very slowly to prevent these forward driving boxes from running hot.

Question 355. How would you block up for a broken engine truck spring or equalizer?

Answer—Raise the front end of the engine by jacks or by running the forward driving wheels up on wedges (having previously blocked on top of boxes), and block between the boxes and truck frame for broken equalizer or between the truck frame and equalizer for broken spring.

Question 356—What would you do for a broken tank spring?

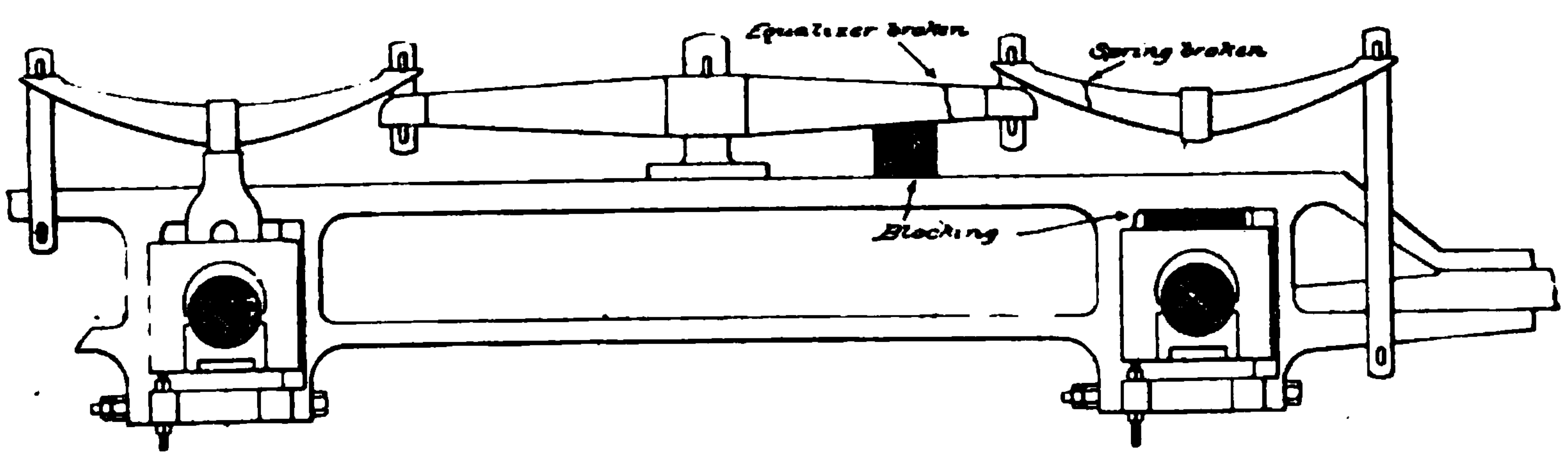
Answer—In many cases a partly broken spring will still carry the tank safely. If badly broken, jack up tank and block over sand board, arch bars, or truck frame as the form of truck requires.

Question 357—If necessary to raise one corner of an engine how else may it be done than by jacks?

Answer—With a piece of iron or coupling pin block on top of the nearest driving box and run this driving wheel up onto a wedge. This should be done carefully to prevent derailment or further damage by running clear over the wedge.

Question 358—How should such a wedge be constructed?

Answer—Of hard wood three to four feet long, about four inches square and tapered from one end to within eight or ten inches of the other. This eight or ten inches of level block will allow the wheel to remain there without running off.



BLOCKING FOR BROKEN SPRING OR EQUALIZER.

Question 359—How would you block up for a broken forward driving spring, spring hanger, or the equalizer on an eight wheel engine?

Answer—Raise the back corner on disabled side, as described in second previous question to take the weight off the front box; then block side on top of forward box; run the back driver off wedge and the forward wheel onto wedge, thus relieving the equalizers; now block the front end of equalizer up level, substitute a chain for a broken hanger if possible; remove the iron from top of back box, let the engine down off wedge and remove all loose parts. For a back spring or hanger do just opposite the above.

Question 360—If the above case were a mogul, what would you do?

Answer—Alternately run the main driving wheel up on a wedge to relieve the weight off the forward driving box, and run the forward wheel up to relieve the main wheel.

Question 361—If on a mogul you found it impossible to properly chain up the forward equalizer, what would you do?

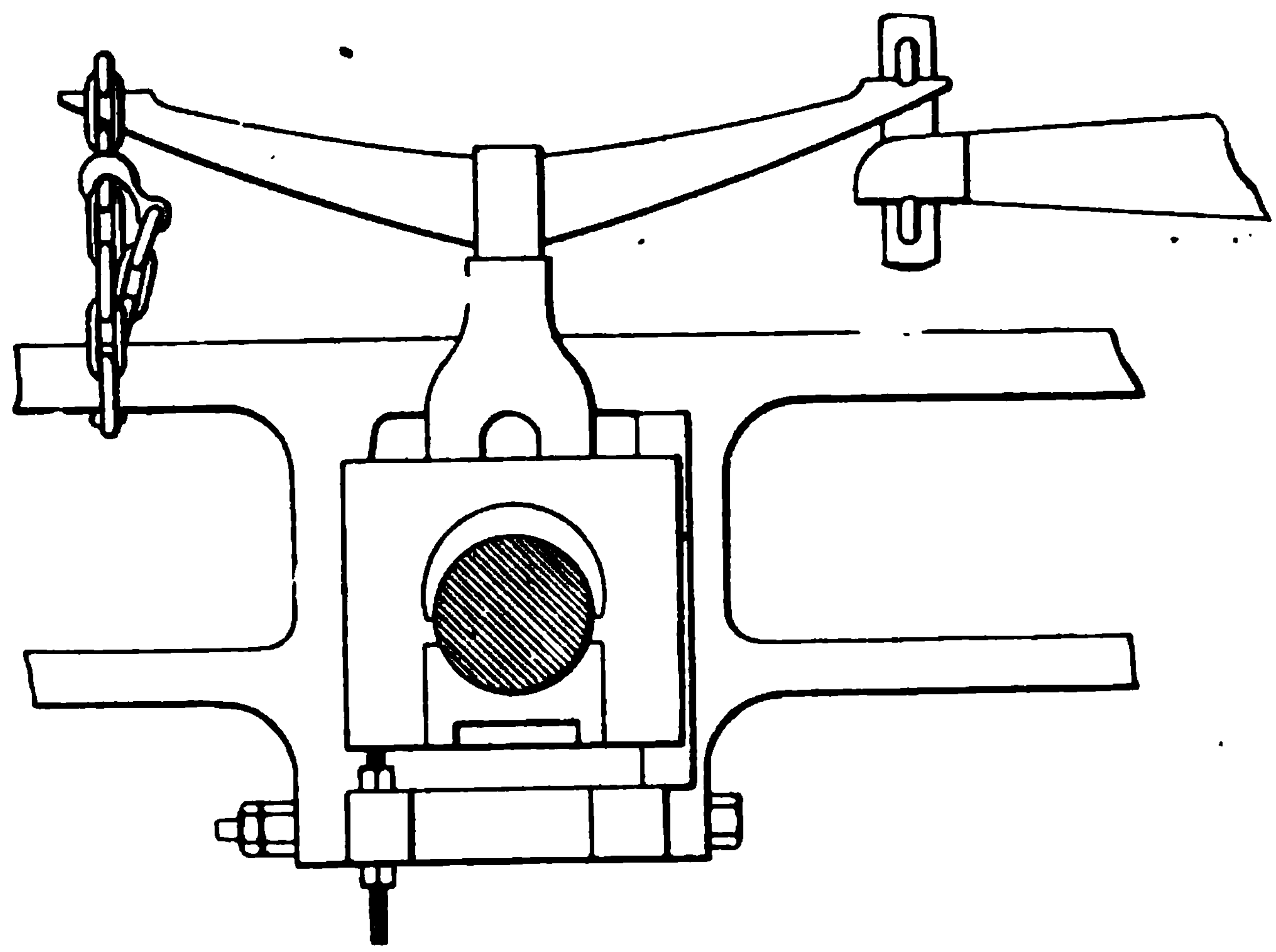
Answer—Block up with wood on top of both the forward boxes or under the front spring saddles, or both; then block the intermediate equalizer.

Question 362—At what points of the frame is the weight of a locomotive carried?

Answer—At the equalizer stands, front and back hangers and at the engine truck center casting.

Question 363—In blocking the crosshead of a locomotive, subsequent to disconnecting, does it make any difference whether it is blocked ahead or back?

Answer—Yes. With engines having their forward driver opposite the guides, the crosshead must be blocked full ahead or the forward crank pin, etc.



USE OF CHAIN TO REPLACE BROKEN SPRING HANGER.

Question 364—In case it became necessary to remove the side rods on such an engine can the engine be run safely?

Answer—Not always. It should be definitely determined that the crosshead pin or key and forward tank pin cannot interfere with each other.

Question 365—In taking off a main rod how are the side rods to be held on the main pin?

Answer—By a wood or iron collar to clamp on the outer end of pin, thus taking the place of the main rod. If there is no such collar on hand, saw pieces of wood to fit the pin lengthwise and tie them securely around the pin.

Question 366—How can you prevent a tank from sweating?

Answer—By applying the heater so as to keep the water warmer than the temperature of the atmosphere.

Question 367—What harm does sweating do?

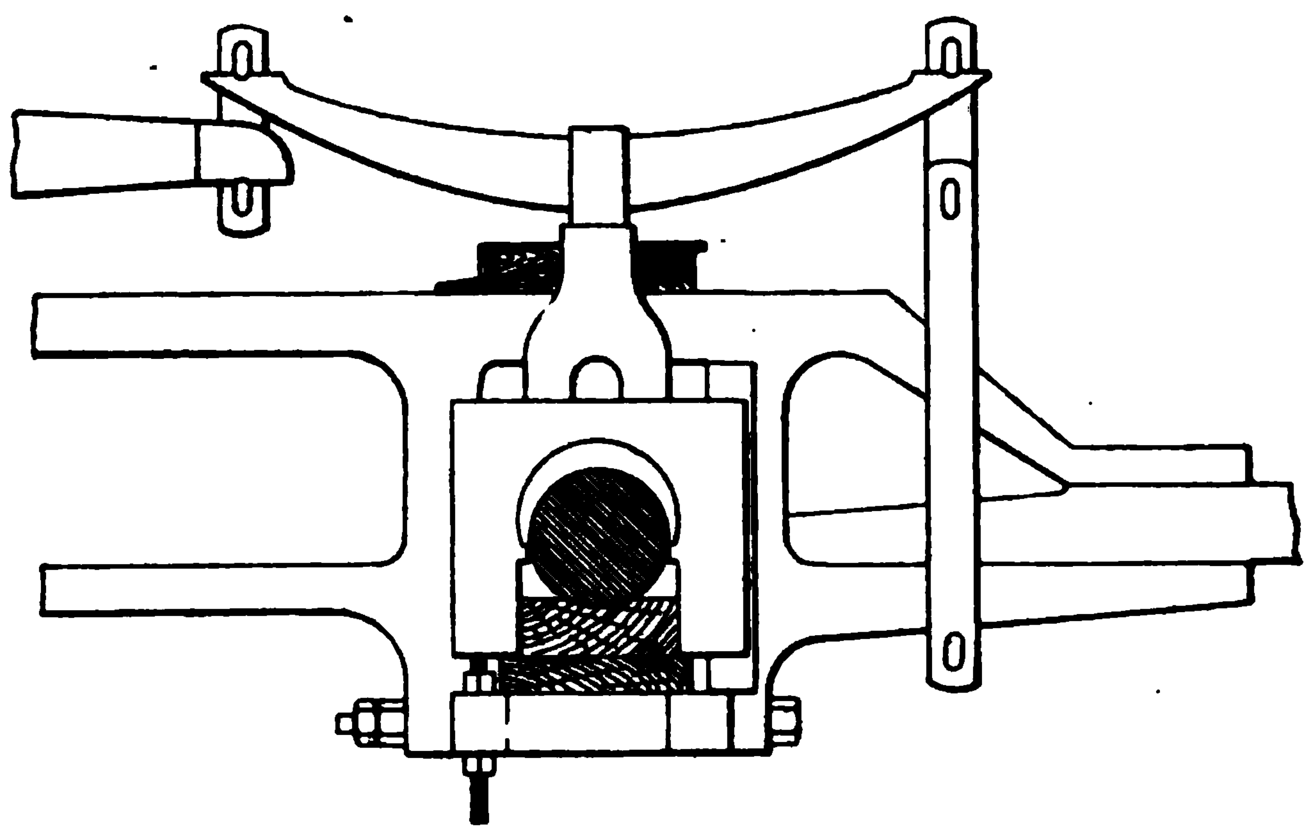
Answer—It deadens the varnish, cracks the paint more or less, and on the road the tank collects more dust and dirt being wet than if it were dry.

Question 368—If you had a broken top rail of frame, what would you do?

Answer—Disconnect on that side and go in with light engine.

Question 369—With a broken jaw, what would you do?

Answer—I would try to take my train in.



BLOCKING FOR DRIVING AXLE BROKEN OUTSIDE THE FRAME.

Question 370—If the cylinder key works out or is lost, what would you do?

Answer—I would replace it with some good iron wedge or cold chisel or else disconnect that side and go in light.

Question 371—If an engine with a broken frame is to be towed, how should it be done?

Answer—Such an engine should not be towed either at the front or rear of a long heavy train as the shocks and strains on the frame are too severe in such a train.

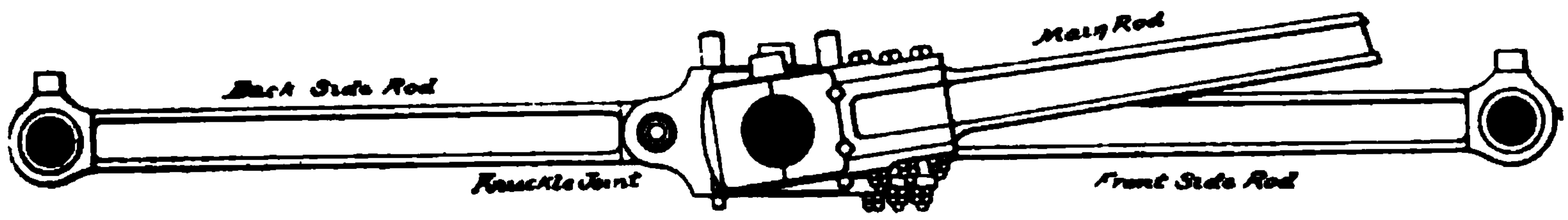
Question 372—What would you do if the frame should break back of the main driver?

Answer—I would take off both back side rods.

Question 373—What would you do if spring of steam-chest relief valve were broken so that steam blowed badly?

Answer—Screw down on the spring or block the valve closed and report it at the end of run.

Question 374—With engines having six or more driving wheels connected, what side rods should be taken off when opposite ones are disabled or broken?

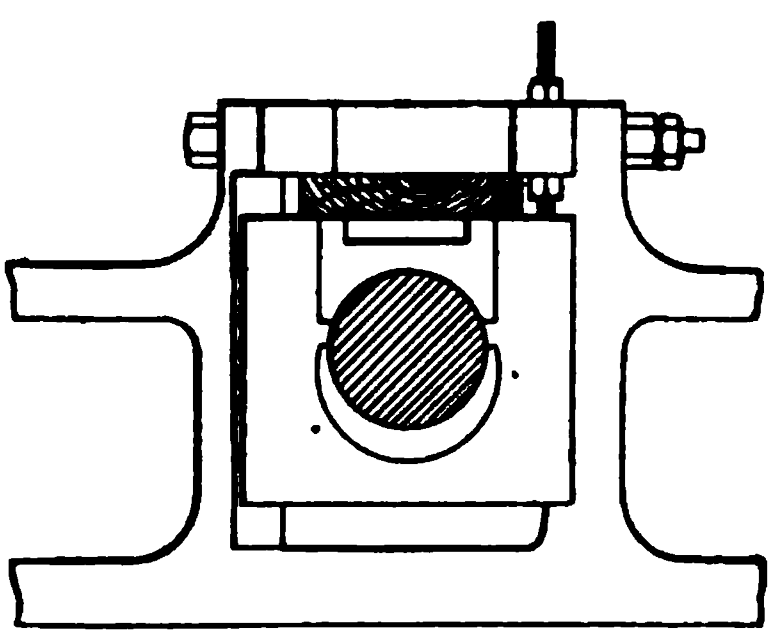


RODS ON MOGUL OR TEN WHEEL LOCOMOTIVE.

Answer—That depends upon where the knuckle pins are located. With the knuckle back of main pin, remove the corresponding opposite rods if the back section is broken; if forward section broken, take off all side rods on both sides.

Question 375—Should you reverse an engine if one side rod should break as you were running along?

Answer—No, you should not, as it would most certainly break the opposite side rod if you did.



BLOCKING UP WHEEL FOR BROKEN AXLE OR TIRE.

Question 376—What could you do with a broken front end or stack?

Answer—Board up the front end if I could or keep a wet blanket over the hole. A barrel or box may be used to obtain some draft in case smoke stack is gone.

Question 377—What would you do if the main tire of a ten (or more) wheel engine should break?

Answer—Run this wheel up on a wedge the thickness of the tire, block between frame and spring saddle, also between pedestal and axle removing collar from disabled wheel. Run in slowly without any train.

Question 378—What if forward tire of such an engine?

Answer—Same as above only take in nearly full train unless rods are sprung.

Question 379—What if back tire of such an engine?

Answer—The same as for the front tire but use great care passing around curves lest the back driver on the other side should drop off the rail. A wedge between tank and engine on good side or a chain from back of engine frame on disabled

side to opposite side of tank, will keep the flange of the back good wheel crowding against the rail. If back end of engine hangs too low, place a tie from the tank to the engine deck and chain back end of frame up to this tie so that the tank will support part of the weight of back end of engine.

Question 380—How does the rod grease cup work?

Answer—By means of a screw plug or piston, the grease in the cup is forced down through the small oil hole onto the pin.

Question 381—If you put water on a pin using grease what is the result?

Answer—It forms soap of the grease and causes it to rapidly disappear from the cup.

Question 382—How would you try to get a leaky or stuck-open boiler check to close?

Answer—Tap it gently on the flange of check, open the "frost" cock and pour cold water over check.

Question 383—What usual precautions must be taken in cold weather?

Answer—Trains must be started and stopped very carefully to prevent breaking draft gear or sliding wheels. If any water or steam is leaking from the tank, be sure the wheels are turning when you start as a brake shoe is very likely to freeze to the wheels and slide them.

Question 384—How can you prevent one injector and its pipes from freezing up while you are using the other?

Answer—By closing the overflow valve and opening the injector throttle sufficiently to allow a little steam to blow back through the injector, supply pipe and hose to the tank. This action is what is technically called "putting on the heater." In addition to this, open the frost cock on the discharge pipe.

Question 385—Where is the frost cock?

Answer—It is located on the discharge or "branch" pipes on either side and at the lowest point, usually a few feet from the boiler check and nearly above the guides.

Question 386—What damage can water do if it escapes from these frost cocks?

Answer—It may freeze on the guides and blow all over the links, eccentrics and running gear of the engine, hence a pipe should lead from these cocks to a point near the ground and this pipe always be seen to be open and not frozen up.

Question 387—What would result from a too free use of the heater?

Answer—The feed water in the tank would become too hot to be taken up by the injector and cause trouble from failure of the injectors.

Question 388—What else should be watched in cold weather?

Answer—The air pump, steam bell-ringer, and electric headlight engine (if you have one). Do not allow any of them to be shut off for any considerable length of time, but keep a little steam flowing through them even though their services are not required. Before taking an engine out of the house in very cold weather, go to the back end of the tank and blow out the rear air brake, air signal and steam heat hose to be sure they are open, as these are near the round house doors and sometimes freeze up.

Question 389—In cold weather why are leaks in the mud ring much worse than at other times?

Answer—Because this water will soon freeze up the ash pan and the dampers and shut off all draft. A steam hose with connection to the syphon cock on top of the dome is carried on many engines in very cold climates. With this hose ice and snow may be melted from the machinery, ash pan and dampers, when necessary.

Question 390—With a hot driving box on an engine what would you do?

Answer—Examine the packing in the cellar, see that the oil holes are open so that oil can feed down the top of box. If very warm, slack off on the wedge or put a block of wood between the frame and spring saddle if possible, so as to take some weight off the box. Use some valve oil on the top of box if it is very warm.

Question 391. At what time of year do the most hot boxes occur?

Answer—During the coldest portion of the winter.

Question 392—Why is this?

Answer—Because then lubrication is the poorest, ice and water get on top of driving boxes and prevent oil from feeding, and the waste in cellars gets frozen stiff so it does not bear against the journal. In very cold weather clean off and put new waste on top of driving boxes frequently.

Question 393—How are many locomotives equipped for cooling hot bearings?

Answer—By water pipes leading to the cellars of every journal on the engine and also the pins.

Question 394—When would you turn water onto a hot bearing?

Answer—Only when, to the best of my judgment, a failure to do so would result in serious delay to my train or other important trains. It is best to endeavor to cool off the bearing by better lubrication than to use water which washes off the oil.

Question 395—Why is it thought best to put the water pipes in the cellars instead of on top of the bearings?

Answer—Because it still allows some oil to be fed down from the top instead of washing it all off.

Question 396—What kind of waste is best for use on cellar-packed journals, such as engine trucks, tank trucks, trailer wheel boxes, and driving box cellars?

Answer—Good, long fibre cotton waste, having been saturated in oil for not less than 24 hours.

Question 397—Why is cotton waste better than wool waste for such purposes?

Answer—Because it has much better capillary attraction and feeds oil *up* much better.

Question 398—How can you prove this?

Answer—By suspending a long cotton cloth and a woolen one with their lower ends in water and then note how much more rapidly the water feeds up the former.

Question 399—Such being the case, why do so many roads use wool waste in all engine truck and driving box cellars?

Answer—Because it has more "spring" to it and hence does not pack down and away from the journal so quickly.

Question 400—What special forms of cotton packing are made with the intent of increasing its spring?

Answer—Various forms of woven and twisted fibre and an ordinary cotton waste with a fine steel shaving running through it to give it spring.

Question 401—If a tender or engine truck box ran hot in spite of your best efforts, what would you do?

Answer—If I had an extra brass on the engine to fit this, jack up the box and remove the brass. In the case of an engine truck this would cause too long a delay to an important train, hence the use of the water pipe on many locomotives.

Question 402—What would you do for a hot crank pin?

Answer—Slack up on the keys (unless it was already too slack and had pounded itself hot), take off the oil cup cover, notice if the oil has been feeding, fill the cup and increase the feed. If the pin is very hot you may have to unscrew the rod cup itself and see that the oil hole is open. If it is not open, put

a piece of waste in the hole of strap, oil with valve oil and proceed to next station without replacing the oil cup. In the meantime clean out the oil hole in the cup and replace it at the first stop.

Question 403—If your rod brasses were babbitted and you noticed a pin getting hot enough to melt the babbitt and was throw-it out, what would you do?

Answer—I would not stop until all babbitt was thrown out and hence oil holes open. Should I stop at once the babbitt would likely close the hole in the strap and oil cup and cause a great deal of trouble in removing it.

Question 404—How can you tell if a wedge is stuck?

Answer—By the hard, stiff way in which an engine rides. It feels like a lumber wagon without springs on a rough road.

Question 405—How would you pull it down?

Answer—Slack off on the lock nuts and try to pry the wedge down or run the wheel over a nut or spike on the rail. Oil well between wedge and driving box.

Question 406—If an engine pounds badly when shut off what would be the cause?

Answer—Flat tires, sometimes loose in the cylinder or main rods too long or too short.

Question 407—In what does the abuse of an engine consist?

Answer—Not taking proper care of or reporting the work to be done on an engine, slipping an engine unnecessarily and catching the engine on sand, reversing an engine while moving, working the engine harder than necessary, pulling or tearing holes in the fire, irregular boiler feeding, and poor firing.

Question 408—Should either injector be used to the exclusion of the other?

Answer—No. Non-use is one of the most frequent injector troubles. Many reliable enginemen think it an excellent plan to use say the right injector going over the road in one direction and the opposite injector on the return trip.

Question 409—Why cannot this be made a good rule to follow on all engines?

Answer—Because many locomotives have one size larger injector on one side than on the other.

Question 410—If an injector is continually used for a heater, what will likely follow?

Answer—The hose strainer gets coated with lime; the boiler check and adjustable parts of injector become covered with scale and stuck.

Question 411—How many miles should an engine run to the pint of lubricating oil?

Answer—That depends upon the size of locomotive and the work it has to do. Most roads feel that 150 miles for valve oil and 50 miles for engine oil, per pint, is a record to be striven for.

Question 412—How many drops are there in a pint of valve oil?

Answer—The following tables from a well known authority will show and also give further data to determine the setting of injector feeds:

Capacity of Lubricators.	Total Number of Drops contained in Lubricator.	Number of Drops for each Cylinder per minute.	Hours consumed in Feeding out a Lubricator.	Total Miles Run on a Basis of		Number of Miles Run to One Pint of Oil on a Basis of	
				Passenger 30 Miles per Hour	Freight 18 Miles per Hour	Passenger 30 Miles per Hou	Freight 18 Miles per Hour.
2 Pints..........	13,200	5 Drops.....	22 Hours	660	396	330	198
3 Pints..........	19,800	5 Drops.....	33 Hours	990	595	330	198
Triple Feed, 3 Pints.....	19,800	5 Drops and 1 Drop for Air Pump.	30 Hours	900	540	300	180

Question 413—What harm is done an engine by sand pipes being stopped up on one side?

Answer—It produces a great strain, often breaking crank pins or rods and also causes an uneven wear of tires.

Question 414—In what ways are automatic bell ringers operated?

Answer—By air or by steam pressure.

Question 415—Which is the better and more generally used?

Answer—Air, because it does not condense or freeze and its exhaust does not obscure the vision, as does condensed steam.

Question 416—In the accompanying cut of the Golmar bell ringer, whose use is quite extensive, how can the adjustment be made so that it will ring the bell properly and yet not turn it over?

Answer—By loosening the lock nut near the top of the vertical stem and lengthening or shortening the rod by screwing in or out on the

GOLMAR BELL RINGER.

set screw. To ring the bell harder make the rod longer, and *vice versa.*

Question 417—How is the bell ringer started and stopped?

Answer—By a small air valve near the throttle and within reach of the engineman. On some engines a small chain or cord connects this air valve with the steam whistle cord so that the bell ringer is automatically started every time the whistle is blown. The air valve is closed, in either case, to stop the bell ringing.

Question 418—Explain the working of the piston and valve as shown in the cut of the Golmar bell ringer.

Answer—At the base is a small cylinder with a piston having two packing rings and just below this piston is the adjustable valve, also having two rings. Compressed air (or steam) enters the opening shown at the left in the engraving and passes through a hole to the interior of the annular shaped valve, pushing the piston upward. An adjustable screw with lock nut is fastened to the bottom of the piston which allows the piston to move a certain distance after which it pulls the valve upwards with it. As the valve moves up it first closes the admission port on the left and then opens the exhaust port on the right hand side in the illustration, whereupon the pressure escapes to the atmosphere. The weight of the bell on the return of its stroke forces the valve and piston down to the lower end of their cylinder again, as shown. The ball joint at the top of piston gives free lateral movement and the sleeve surrounding the piston rod is free to move upward with the bell several inches farther than the travel of the piston and its rod.

Question 419—Particularly in the western parts of the United States, what causes the greatest trouble with locomotives?

Answer—Poor water. It has been estimated that the poor water on western railroads necessitate an additional expense of about $750 a year for each locomotive in service.

Question 420—What is meant by poor water?

Answer—Generally speaking, "hard" water, that is, water having incrustating matter which causes foaming and sometimes acids which eat into the flues and boiler sheets.

Question 421—If these solids are in solution why should they cause trouble in a locomotive boiler?

Answer—Because when such large quantities of water are evaporated, the solid matter remains as a sediment, some portions of which form a coating over the flues and sheets thus preventing the water from coming in direct contact with the

iron. The result is the iron becomes overheated and cracks, and with all its over-heating less heat is imparted to the water in the boiler.

Question 422—How much of these incrustating solids are contained in a given quantity of hard water?

Answer—This varies greatly from two to twenty pounds per 1,000 gallons.

Question 423—How can much of this solid matter be gotten rid of after the water is evaporated?

Answer—By blowing it out of the boiler.

Question 424—How is this done?

Answer—One or more blow-off cocks are placed in various parts of the boiler—generally just above the mud ring, as there is where the most of the sediment settles.

Question 425—How are these blow-off cocks operated?

Answer—By hand or by pneumatic (or steam) pistons attached to the valves.

LIST OF PARTS.

A—Shell.
B—Piece that screws in boiler.
C—Piston.
D—Inner valve
E—Outer valve.
F—Inner valve seat.
G—Outer valve seat.
H—Top plate.
I—Handle for closing by hand.
N—Spring.
J—Large spannernut.
K—Smaller.
L—Piston ring.
M—Flat head bolt for holding inner valve.

MCINTOSH BLOW-OFF COCK.

The accompanying illustration shows the construction of a type of such valve which is largely used in this country. A small valve in the cab admits air or steam to a pipe leading to the top of piston C whose steam forces open both outer and inner valves D and E, allowing water and sediment to escape from the boilers

to the large outer discharge pipe leading to the side or behind the engine. By shutting off the cab valve a spring H aided by boiler pressure under both valves D and E close them.

Question 426—What care should be given these blow-off cocks?

Answer—At least once a month the cap H of the cylinder should be removed and the cylinder wiped out and oiled.

Question 427—How can this valve be opened or closed by hand in case there is no pressure to operate it?

Answer—To open it screw in on the tail shaped nut at the top; to close it, screw this out.

Question 428—What effort is made by many railroads to overcome the bad effects of "hard" water?

Answer—Some kind of boiler compound, such as soda-ash, is put in the locomotive tank each trip. This forms a chemical action with some of the incrustating solids causing less incrustation, but leaving more sediment which must be blown out or will cause foaming in boilers.

Question 429—What other means are railroads adopting?

Answer—The chemical treatment of water in large settling tanks located at the various water stations where poor water is had. The solids are allowed to settle and the clear and almost soft water above is pumped into the water tanks and then used for locomotives.

Question 430—If your engine should get off the track with one or more wheels, how would you proceed to get it on again?

Answer—Conditions vary in every case. If the wheels are close to the rails, block up with oak blocks or wedges to a pair of good wrecking frogs (car replacers) and run the engine up on the track. It is a general rule to follow that an engine will go on best and most easily by retracing the path whence it got off.

Question 431—In case of derailment, what should you do first?

Answer—Look the situation over carefully, see how the engine stands, that the water and fire in the boiler are safe; if the wreck is serious telegraph for another engine and wrecking outfit; if not so serious, wire for another engine to help pull you on; if you think possible to move the engine alone, put down some blocks and try it before sending for help.

WRECKING FROGS OR CAR REPLACERS.

Question 432—If the rails are spread to what gauge should they be spiked?

Answer—Four feet eight and one-half inches on straight track and about one-half an inch or more on sharp curves.

Question 433—After your engine is back on the track again, what would you look for?

Answer—Broken driving box cellars, bent or sprung rods or crank pins, broken draw castings or draw bars, broken brake rigging, sprung axle or journal.

Question 434—Suppose a driving box cellar or its lugs were broken, what would you do?

Answer—I would make one of wood or in some way block on top of the binder sufficiently to hold the packing against the journal.

Question 435—Why is it not safe to run an engine with a sharp flange?

Answer—Because it is very likely to catch a switch point or a frog and cause derailment, or the flange may break and cause a bad wreck.

Question 436—Are there any locomotives that cannot run under their own steam with their side rods off?

Answer—Yes. In the extreme effort of modern builders to get long main rods and short straight eccentric blades. In order to do this the eccentrics are not placed upon the main driving wheel axle but upon one of the driving wheel axles ahead thereof. Hence, with the side rods off the least slip of the main drivers would throw them out of tram with the driving wheel carrying the eccentrics, consequently such an engine would have to be towed in. This construction is becoming quite common for switching locomotives, which class of power is, of course, seldom out on the road where delays from breakdowns are most serious.

Question 437—If you had, say, a disabled cylinder and had no drift to disconnect valve stem, what would you do?

Answer—Take out top rocker arm pin, pull the valve rod an inch out of line with the top rocker arm and brace it there securely by a notched-end stick. Disconnect main rod and clamp valve in center, and block crosshead, of course.

Question 438—On very large locomotives with heavy rods is there any way to avoid taking down and loading up the main rod?

Answer—Yes. If the main rod goes through a yoke at back of guides, take down the back end of main rod and block the crosshead ahead, letting the main rod rest in the bottom of this yoke.

Question 439—If you broke a main pin on an engine having six or more wheels connected, what rods would you take down?

Answer—All rods on disabled side and all side rods opposite. Use very light throttle so as not to slip as you are only working one wheel on one side.

Question 440—In running an engine on one side how can you almost entirely prevent stopping on the dead center?

Answer—By stopping the engine with the reverse lever, giving her little steam. When the engine has stopped and before she starts to back up, set the brake hard, close the throttle and open the cylinder cocks.

Question 441—Why will this be quite certain to keep the engine off dead center?

Answer—Because the power to stop the engine being entirely in the cylinder of the good side, the greater power is on the quarter and is nothing on the dead center to cause the engine to stop at that point.

Question 442—In blocking a crosshead should you place it as far forward or as far back as it is possible to do?

Answer—No. Put a small block at the front or back end of crosshead, as the case may be, in order to prevent all possibility of the cylinder packing rings dropping into the counter bore.

Question 443—What harm would that do?

Answer—It might necessitate the removal of the adjacent cylinder head and if a back one it is a long, expensive job.

Question 444—If a side rod pin breaks what would you do?

Answer—Take off the same side rod on the opposite side. Should the engine have six or more drivers connected and the knuckle is not in the rod removed, it will be necessary to take down all side rods on both sides.

Question 445—If your guides got hot, would you cool them off by water?

Answer—Never. It would warp them. If they were too close loosen the bolts and put in a thin liner.

Question 446—What are your duties as an engineer after arrival at terminal roundhouse?

Answer—Inspect my engine carefully, closing all oil cups as I go around, and make a full report on proper form or work book of any defects or necessary work to be done, not overlooking the condition of fire-box, flues and boiler, and if in need of washing out.

Question 447—How would you block up for a broken tire?

Answer—Run the broken wheel up on a wedge a little thicker than the tire, say five inches. Remove the driving box cellar and block solid with hard wood, blocking under the driving box. If the rods are not sprung or broken leave on. Block or chain to the frame the equalizer ends each side of this wheel. Run the engine off the wedge and pull your full train to the terminal, watching closely that blocking remains in place. Most locomotives to-day have all tires flanged, but should your engine in this case have several blind or "bald" tires, in blocking up a flange tire be very careful to see that your engine curves properly or else run very slow. Sometimes blocking a swing engine truck will keep the engine to the track.

Question 448—If you were at some isolated point on a branch line and had either a burst steam pipe or a demolished steam chest, what would you do to get in?

Answer—Knock the fire, open the front end, split or loosen the nuts at top and bottom of steam pipe, remove the top or bottom joint ring as the case requires and put in its place a piece of board covered with sheet iron (or piece of old scoop shovel), tighten up with new nuts if obtainable, fire up the engine, disconnect disabled side and go. In case of demolished steam chest, blocking the steam ports is often more easily and quickly done, as explained elsewhere herein.

Question 449—In disconnecting, how do some authorities advocate doing?

Answer—With good solid crosshead blocking on hand, to always block the piston ahead, take out forward cylinder cock or loosen front cylinder head, and clamp the valve ahead far enough to admit a little steam to back side of piston. The purpose of this steam in cylinder is to prevent its moving.

Question 450—How would you arrange to run a mogul or consolidation engine without the pony truck?

Answer—Raise the engine in front and block between the cross-equalizer and the belly of the boiler.

Question 451—If a cast iron tender or engine truck wheel should break, what would you do?

Answer—Try to block it from turning and skid it to the nearest siding, running very slowly. Then chain up or remove the broken wheel.

Question 452—Which man is the most economical of oil, steam, coal *and time*, he who continually carries a boiler too full of water or he who carries several inches less than a full glass?

Answer—Most decidedly the latter. High water men make the poorest records and are the most extravagant besides frequently breaking cylinder heads, shearing crosshead keys or breaking pins. If you keep close watch of the high water man on the road, you will find that there are many times when his water goes much lower than the other man; for working wet steam first takes too much water from the boiler, then the water supply is increased, steam drops back, the reverse lever is dropped lower to make up for this loss of pressure; this takes still more water and if the run is long and hard it will be difficult to keep the water outside the lower water glass nut.

FRICTION AND LUBRICATION.

Question 453—What is friction?

Answer—It is force of resistance tending to prevent the motion of two bodies in contact.

Question 454—Upon what does the amount of friction depend?

Answer—It depends upon the smoothness or roughness of the surfaces in contact; upon the pressure of the one part upon the other part; upon the composition of the material in contact; upon the kind of lubricant used; upon the speed and upon the temperature.

Question 455—Which is the greater, the friction of fluids or the friction of solids?

Answer—The friction of solids is far greater.

Question 456—What is the object of using lubricating oils between frictional surfaces?

Answer—In order to substitute the friction of fluids in place of the friction of solids; for with a thin film of fluid covering the two parts the contact will be between these fluids instead of being between solids. Oil creates a film and tends to keep the rubbing surfaces apart, thus greatly lessening the friction.

Question 457—About what portion of the total power of a locomotive is wasted in friction?

Answer—From 10 to 25 per cent, depending upon the effectiveness of the lubrication and the balancing of the valves.

Question 458—What part of a locomotive has the greater friction resistance?

Answer—The valve, but this is greatly reduced by well balanced valves.

Question 459—What does proper lubrication prevent?

Answer—It prevents wear, heat and resistance.

Question 460—How much oil is useful and necessary for proper lubrication?

Answer—Only the amount that can adhere to the frictional surfaces. Too much oil in cellars and on bearings only runs onto the ground or is thrown all over the engine; too much oil in cylinders only gums up the exhaust passages and nozzles.

Question 461—What is the purpose of graphite, soap, ammonia, salt, etc., on a hot bearing?

Answer—Chiefly to fill up or glaze over the rough spots in the bearing surfaces, also these substances will stand a greater heat than oil before running off the bearing.

Question 462—What is one frequent cause for hot bearings?

Answer—The waist in cellars being too high at the sides, so that threads of it are caught up by the journal and wrapped around it, often catching fire when both journal and box are cold.

Question 463—What is the best material for packing the cocks in the cab to keep them steam tight and still have them work easily?

Answer—Fill the glands with plumbago or graphite with a ring of asbestos wicking each side, then tighten down solid.

Question 464—In case of impending collision, what should you do?

Answer—Apply the air brakes in emergency, shut off the throttle, whistle for brakes, open wide the sand lever and then protect myself as my best judgment dictates.

Question 465—Should a man make up his mind before hand what to do?

Answer—Most assuredly. When in great danger a man has little time for thinking and should act correctly from his premeditated determination. There have been many cases where men acting on the spur of the moment have released their brakes and done other things that tended not in the least to reduce the force of collision.

Question 466—Would you not reverse the engine in such emergency?

Answer—Not unless I had a very poor driver brake or none at all. The accompanying table of tests showing the distances and other results of stopping engines with and without trains, by reversing and by not reversing, using sand and without sand, etc., will clearly show what the most efficient practice is:

Test No.	BRAKES USED.	CONDITION OF TRAIN.	Speed.	Sand Used?	Total No. of Stops made	Maximum Length of Stops.	Minimum Length of Stops.	Average Stop in Feet.	Time in Seconds.	Wheels Slid?	Flat Spots.
1	Driver and Tender Brakes	Engine and Tender	30	No	9	280	240	254	11	No	No
2	Driver Brake alone	Engine and Tender	30	No	2	438	387	412	18	No	No
3	Tender Brake alone	Engine and Tender	30	No	7	604	458	538	23	No	No
4	No Brakes, Engines Reversed	Engine and Tender	30	No	3	464	426	450	20	Locked and Revolved Backwards.	No
5	Driver and Tender Brakes and Engine Reversed	Engine and Tender	30	No	4	290	245	276'	12	Yes	2⅛-in
6	No Brakes and Engine "Plugged"	Engine and Tender	30	No	2	540	505	522	25	Locked and Revolved Backwards.	No
7	Driver and Tender Brakes	Engine and Tender	30	Abundance	1	260	260	260	11	No	No
8	No Brakes and Engine Reversed	Engine and Tender	30	Abundance	1	280	280	280	12	No	No
9	No Brakes and Engine "Plugged"	Engine and Tender	30	Abundance	1	265	265	265	11	No	No
10	Driver and Tender Brakes and Engine Reversed	Engine and Tender	30	No Fresh Sand	4	177	140	158	9	No	No
11	Driver and Tender Brakes, with Engine "Plugged"	Engine and Tender	30	No Fresh Sand	1	177	177	177	9	No	No
12	Driver and Tender Brakes	Engine and Tender	20	No	1	111	111	111	8	No	No
13	No Brakes and Engine Reversed	Engine and Tender	20	No	1	161	161	161	9	No	No
14	Driver and Tender Brakes	Engine and Tender	20	Yes	1	90	90	90	6	No	No
15	Driver and Tender Brakes	Engine and Tender	40	No	1	532	532	532	25	No	No
16	No Brakes, Engine Reversed	Engine and Tender	40	No	2	861	820	840	32	Locked and Revolved Backwards.	No
17	Driver and Tender Brakes	Engine and Tender	40	Yes	1	475	475	475	20	No	No
18	All Brakes Cut in	Eng ne, Tender and 5 Coaches	30	No	8	271	260	258	11	No	No
19	All Brakes Cut in	Engine, Tender and 5 Coaches	30	Yes	1	250	250	250	11	No	No
20	All Brakes Cut in, Engine Reversed	Engine, Tender and 5 Coaches	30	Yes	7	335	199	265	11	Yes	3-in.
21	All Brakes Cut in	Engine, Tender and 5 Coaches	40	No	4	500	400	474	19	No	No
22	All Brakes Cut in	Engine, Tender and 5 Coaches	40	Abundance	1	475	475	475	19	No	No
23	All Brakes Cut in, Engine Reversed	Engine, Tender and 5 Coaches	40	Yes	1	342	542	542	23	Yes	4-in.
24	All Brakes Cut in	Engine, Tender, 5 Coaches and 4 Sleepers	30	No	1	327	327	327	14	No	No
25	All Brakes Cut in	Engine, Tender, 5 Coaches and 4 Sleepers	35	No	1	465	465	465	19	No	No
26	All Brakes Cut in	Engine, Tender, 5 Coaches and 4 Sleepers	40	No	2	575	575	575	25	No	No
27	All Brakes Cut in	Engine, Tender and 4 Sleepers	30	No	1	367	367	367	14	No	No
28	All Brakes Cut in	Engine, Tender and 4 Sleepers	40	No	1	702	702	702	26	No	No
29*	All Brakes Cut in, Engine Reversed	Engine, Tender and 5 Coaches	30	Yes	9	375	218	350	13	Yes	2¾-in
30†	All Brakes Cut in, Engine Reversed	Engine, Tender and 5 Coaches	30	Yes	1	325	325	325	13	No	No
31*	All Brakes Cut in	Engine, Tender and 5 Coaches	30	Yes,	1	375	375	375	14	Yes	3-in.
32	Sleeper "Kicked"		30	No	1	416	416	416	18	No	No
33	Coach "Kicked"		30	No	1	202	202	202	10	No	No

* Unexpected Emergencies. † Expected Emergency.

Question 467—With the modern large locomotives is it generally safer to jump off or remain behind the boiler head in case of collision?

Answer—That depends greatly upon the kind of collision. If a rear-end collision, less damage is likely to your locomotive. If a head-end collision with another large locomotive, I should "unload" at once. Going at moderate speed and in a safe place to jump, I would certainly get off. If it were in a cut the cars behind are likely to pile up and render it as dangerous for you as it would be behind the big boiler head.

LOCOMOTIVE MECHANICAL STOKER.

As most modern stationary and marine boilers are equipped with some style of automatic stokers, it may readily be imagined that not a little inventive genius and experimental work has been expended in an effort to obtain a practical and efficient locomotive boiler stoker. There is a strong opinion prevailing that the day will come when much of the hot and laborious work now performed by the locomotive fireman will be done, with much saving in labor and coal, by automatic machinery. As locomotives of larger and yet larger size are constructed, some easier means of firing them is bound to come into more general use.

Probably the most practical device of this kind that has yet been devised and used to any extent, is the invention of an experienced railway engineer, John W. Kincaid, and will be briefly described and illustrated in the following pages.

In the above illustration the side of the locomotive is cut away to show the Stoker in position on the deck when attached to the door of the firebox and in operation, and to show its relative size. A very short decked engine has been purposely selected in order to show that there is plenty of room around the Stoker

This locomotive stoker is a compact little machine, as shown above, and when in use occupies the deck of the engine directly in front of the fire-box door, leaving sufficient room for the engineer and fireman on either side. It is applied to the locomotive fire-box by removing the door and substituting the one attached to the stoker. This door is held in position by means of the lugs on either side, as shown in views III and IV. A connection is then made between the blower pipe of the locomotive and the pipe union on the front end of the stoker and feeding steam to the stoker engines. Thus the stoker can be attached in a few minutes. In view No. I the stoker is shown as attached to the furnace door of a locomotive; the hopper for holding coal and the plunger trough below. The engines and steam pipe extending to the union just described; also the valves at the left of stoker in position for the fireman to conveniently regulate and operate the machine.

VIEW NO. I.—SHOWING STOKER FROM LEFT AND REAR.

The machine consists of four principal parts: a hopper A; a trough B; a stoker engine cylinder C, with its steam valves D; and a controlling engine F. (See View I.)

The hopper A, the lower part of which is in the form of two semi-cylindrical channels in each of which is a spiral conveyor, whose shafts *a*-2 (see View IV), are journaled in its front and rear ends; and an upper part which is formed into a convenient shape to hold the coal. This whole hopper is arranged so that it hinges on the journals of one conveyor shaft *a*-2, so that the whole may be swung over to one side and out of the way (see view II), should it be necessary when the engine is standing in the roundhouse for the hostler to put in fire with a scoop through the opening or small door *b*-3, in furnace door E above the trough B.

These bearings for this conveyor shaft upon which the hopper hinges are parts of brackets bolted to the stoker cylinder C, and to the trough B.

The twin spiral conveyors (see View IV) keep feeding the fuel toward the forward end of the hopper, whence it passes through an opening A (see View II) in its bottom, falling in the trough B in front of the plunger B, unless the plunger is extended in process of delivering the previous charge of coal to the furnace (see View II) in which case the coal falls upon an apron *b*-4 (see Views II and III), which is attached to the plunger B, and reciprocates in the space between the hopper A and cylinder C of the main engine for the purpose of closing the hole A (see View II) to prevent coal from falling behind the plunger head. When the piston is retracted (see View II) carrying the plunger B at its end, and the apron *b*-4 which is secured to this plunger B, the coal drops into the trough or channel B and is carried forward into the furnace on its next stroke.

The trough has a small opening *b*-1 (see Views I and II) in its bottom at the end nearest the cylinder C through which any dust which may accumulate behind the plunger is discharged.

VIEW NO. II.

Same as No. 1, except hopper turned over in order to permit scoop being used to fire up engine in roundhouse.

This illustration gives a more complete view of the upper portion of the engines, and the ratchets by which the spiral conveyors are rotated. It also shows the opening in the door furnished with the Stoker, and the hinged door covering same, which can also be elevated when the hopper is down, admitting of hooking up the fire (should it be necessary) without moving hopper. This illustration shows the hood covering the mechanism of Stoker engines when lowered to position

Integral with the rear head of cylinder C is formed the valve-chest H of the controlling engine F (see Views I and II). This controlling engine F is placed with its line of action vertical, and has on the upper end of its piston-rod G (see View II), a cross-head *g*-1 which operates two ratchet levers *g*-2 and *g*-3 pivoted on conveyor shafts *a*-2. On the rear face of the cross-head *g*-1 is a projecting lug arranged to operate the stem of the small controlling valve *h*-1 through two adjustable collars *h*-3 and *h*-4, which it engages on its upward and downward strokes respectively, moving the controlling valve to admit the steam to the proper end of the floating valve *h*-2, which, in turn, admits steam to the proper end of the cylinder F. In this manner the conveyors are moved intermittently by the controlling engine, each downward stroke of the controlling engine moving the conveyors one or two teeth of the ratchets *g*-4 and *g*-5.

VIEW NO. III.

Giving view of stoker from right side of interior of fire-box.

This is a transverse view from No. 1, and shows the head of plunger and its position in trough, a portion of the forward end of the right-hand spiral conveyor, also the ratchet and three cams directly in front of same, which regulates the strokes of the plunger The conical deflector, which spreads the coal in front of and below the trough in which the plunger travels, is shown in this cut.

On the shaft of the conveyor *a*-2 (see Views III and IV) and immediately in front of ratchet *g*-5 is a series of cams. These cams operate levers immediately behind them and not shown in views. These levers communicate action to the valves which control the velocities of the different strokes of the plunger. On the left side of the steam-chest D are arranged three small throttle valves, *d*-4, *d*-5, and *d*-6 (see Views I and II). As the conveyor revolves it opens these valves consecutively, first for light stroke of the plunger, throwing the coal near the door, second for a stroke

of medium speed, distributing the coal in the middle of the furnace, and third, giving the stroke of greatest velocity, sending the coal to the forward end of the furnace. By this arrangement of valves, it is easy to control the firing of the machine, first by regulating the speed of the controlling engine F, and thus the amount of coal delivered to the furnace in a given time. Should the fire bank in any portion of the furnace, the distribution of the coal may be changed at will by varying the effective port openings by means of the three throttle valves *d*-4, *d*-5, and *d*-6, before mentioned (see Views I and II). The machine carries two lugs *b*-8 (see View II), which secure it to the furnace door E, but in such a manner that it may be removed and drawn back on the coal heap should it be crippled by any accident, and so allow the furnace to be fired with the scoop in the usual manner, preventing any delay to the train by reason of an accident to the stoker. This connecting operation has been performed a number of times in about one minute. However, the locomotive may be fired by scoop while the stoker remains in position, shown in View II.

VIEW NO. IV.

Same view as No. III with hopper turned over to the right.

This view shows the twin spiral conveyors and the front bearings of the shafts on which they rotate, the end of trough with the plunger retracted; also the hole through which the coal drops on leaving conveyors, to be forced into the fire-box by the next movement of the plunger

Each machine is fitted with a furnace door E, shown in Views. This door has standard hinges and latch, and is of the usual shape and size, but has an opening through it of proper shape to receive the end of the machine, and has bolted to inner face a conical deflector which is a part of the device for uniform distribution of the

coal over the whole grate area. View III shows the shape of the front end of the hopper, which is cut down as shown to enable the fireman to hook up the fire, if necessary, through opening of door B without turning over the hopper. A hood is attached to the hopper under the rear part of same, reaching down and covering the working parts shown in View I.

ADVANTAGES CLAIMED.

1. A saving of coal and successful use of a finer and cheaper grade of coal than usual with manual firing at smaller charges are put in more frequently than with a scoop.

2. Great reduction of black smoke due to only a small amount of coal being put into the fire-box at one time.

3. The work of the fireman is lessened and consequently he has more time to look for signals and perform his other duties. It is also much cooler work for the fireman as the fire-box door is not opened.

4. By maintaining a uniform fire-box temperature and avoiding opening the fire door, boilers are less likely to leak and hence fire-box sheets and flues will last longer and save boiler repairs.

5. It improves the steaming of an engine to such an extent that larger exhaust nozzles can be used, thus reducing the back pressure in the locomotive cylinders.

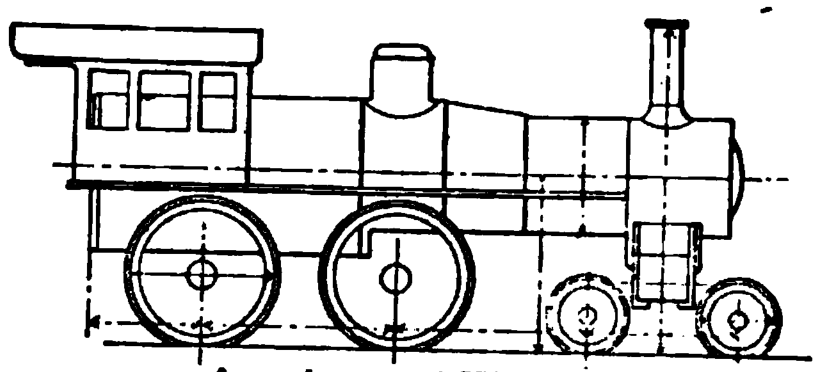
6. Less stuck grates and banked fires than by manual firing.

7. More perfect combustion than where the fire door is frequently opened and heavy charges put in the fire-box.

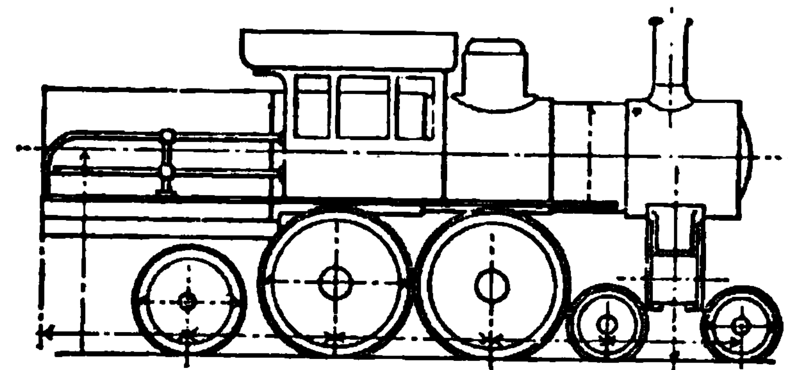
LOCOMOTIVE CLASSIFICATION.

There have been so many terms used in describing the various classes of engines that it is often confusing to one not versed in colloquialisms. Such names as "pony," "dinky," "spider," "camel," "hog," "ocean liner" and "prairie schooner" may be characteristic and strongly flavored with the railroad man's sense of fitness, but they do not always convey the correct meaning to men in other localities, hence we deem it wise herein to illustrate the more proper terms to apply to the various classes.

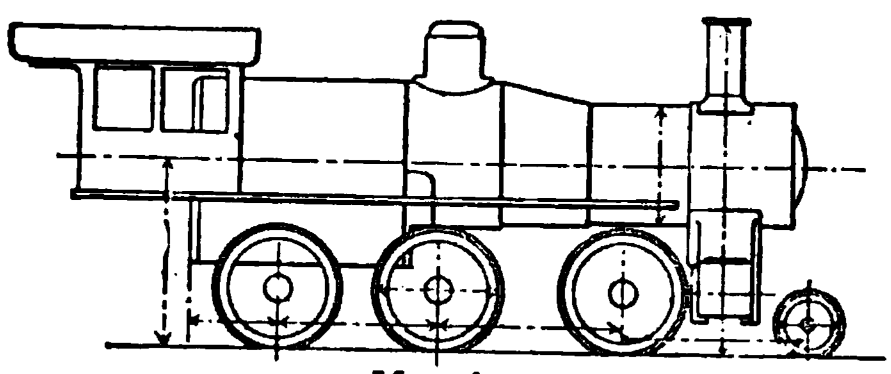
A very simple and ingenious classification of locomotives, devised by Mr. F. M. Whyte, has been adopted by several of the large locomotive builders of the United States. The idea is to eliminate the type name entirely, using numbers to show the three groups of wheels under the locomotive, namely (1) engine truck wheels, (2) driving wheels, and (3) trailing wheels.



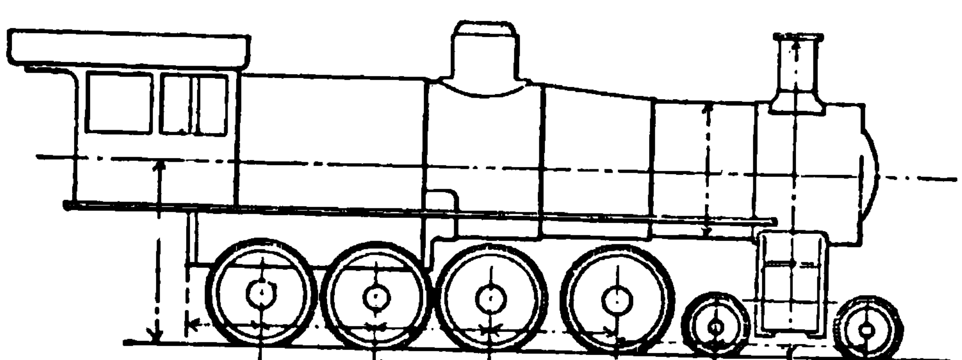
American or 8 Wheel



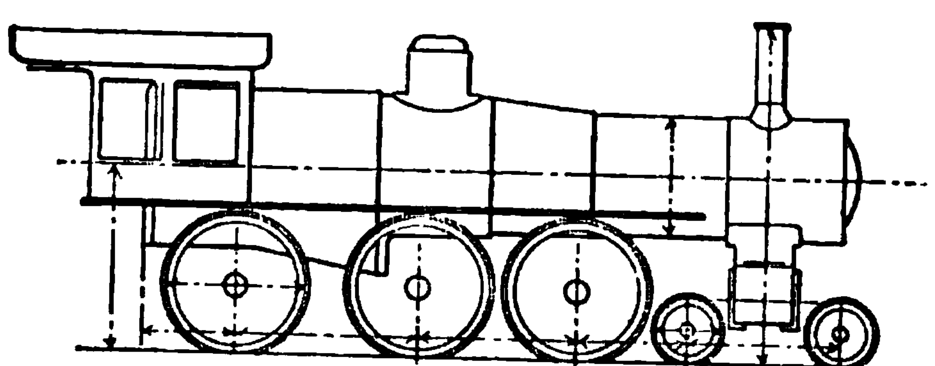
Atlantic



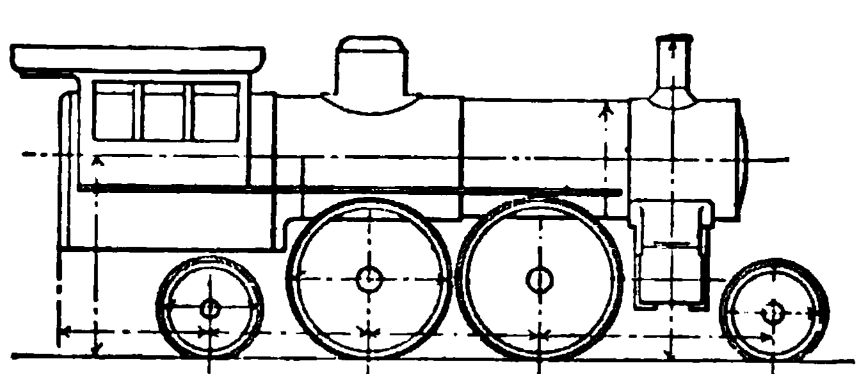
Mogul



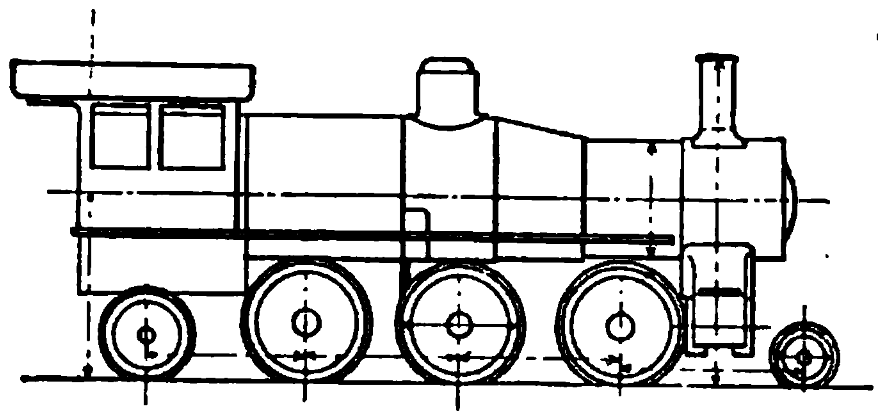
Mastodon or 12 Wheel



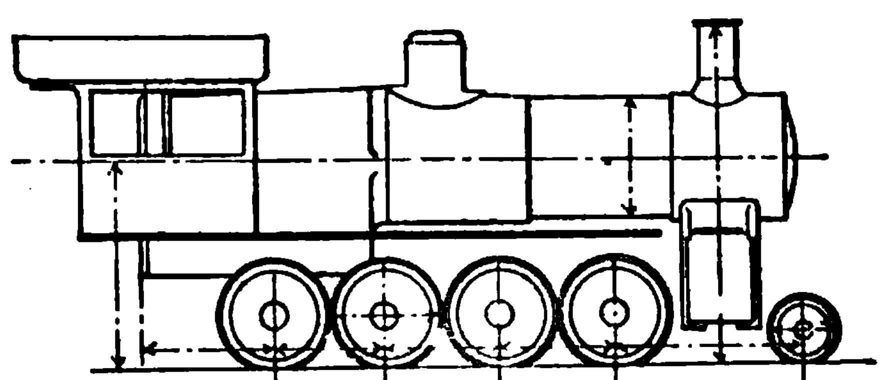
Ten Wheeler



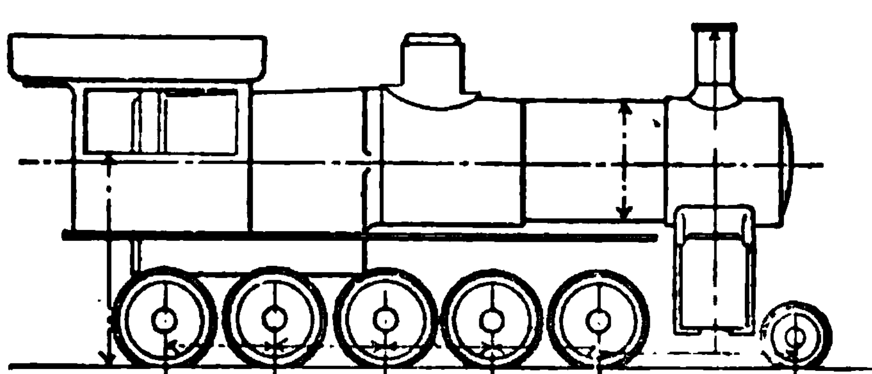
Columbia



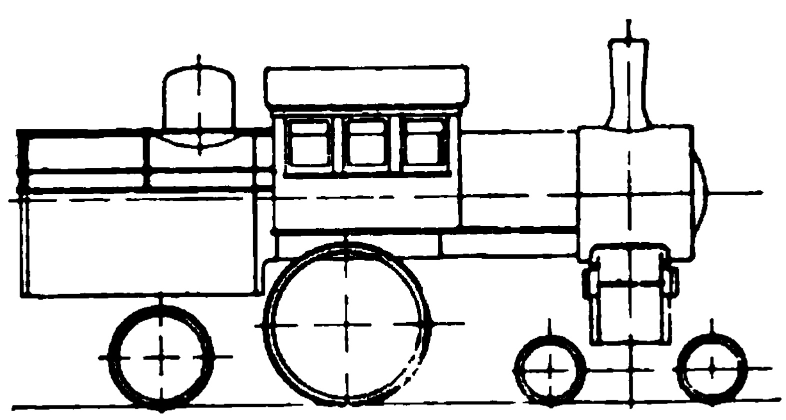
Prairie



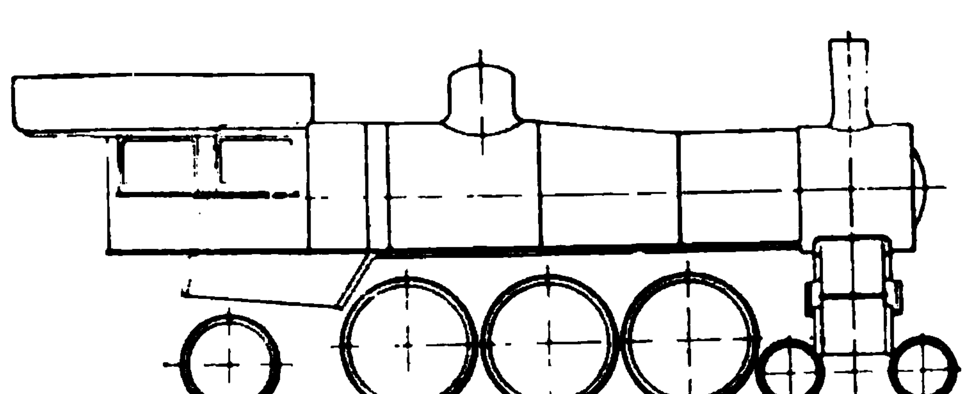
Consolidation



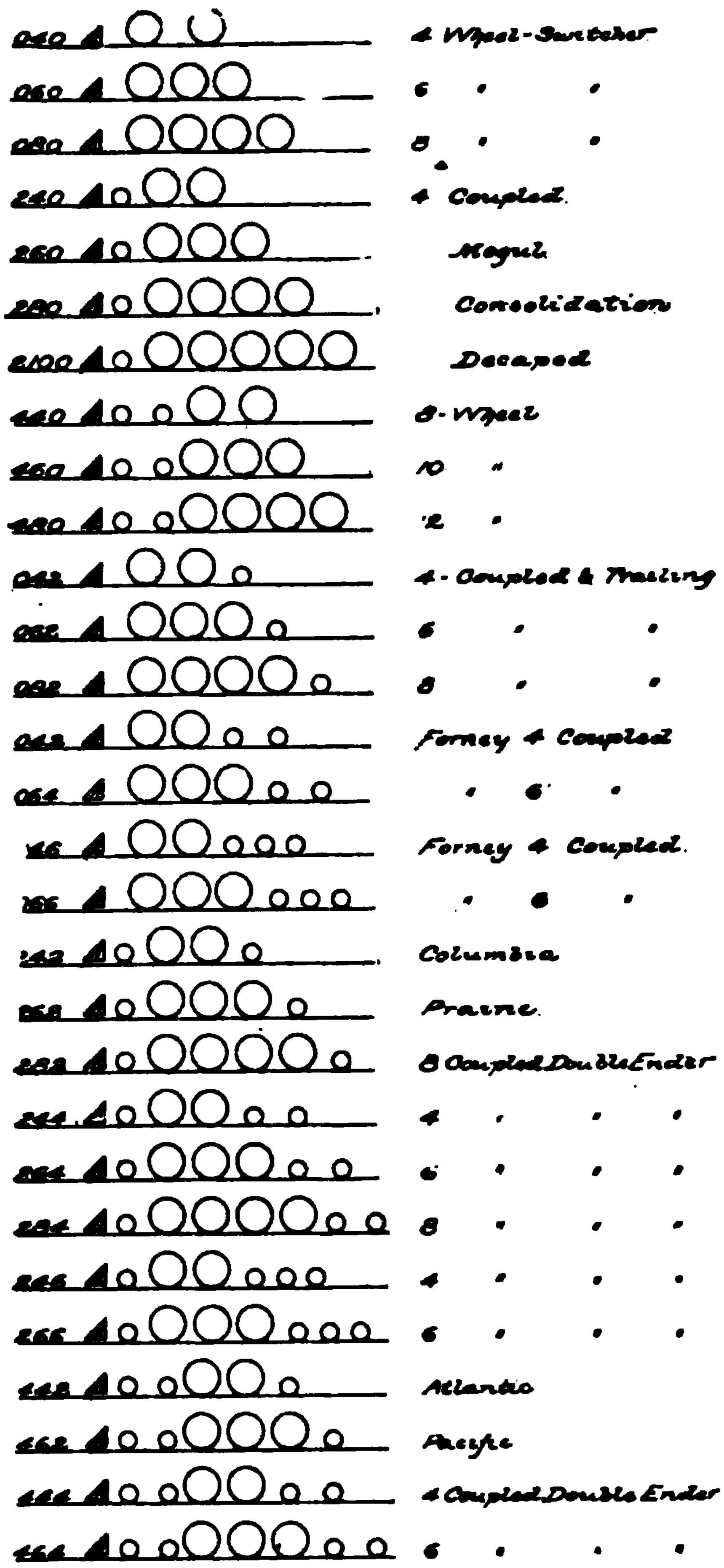
Decapod



Single Driver.



Pacific.



WHYTE'S SYSTEM OF CLASSIFICATION.

The three indicative wheel figures may be separated by hyphens, thus, 4-4-0 or written 440. Where the tender is carried on the same frame as the engine, it will be noticed that the tender wheels are included in the figures and the letter "T" added.

In order to give an adequate idea of the size of a locomotive and whether simple or compound, the letter "C" is used to denote compound and following the wheel arrangement is given the number of thousand pounds the engine weighs, exclusive of the tender. Thus a compound Atlantic engine weighing 160,000 pounds would be classed 442-C-160, or 4-4-2 C 160.

ELECTRICITY

CHAPTER I.

THE PRINCIPAL ELECTRIC UNITS.

Whenever an electric current is flowing in any circuit an expenditure of energy takes place, since there is no known substance that does not resist the flow of current through it, and in order to overcome this resistance and cause current to flow, pressure must be brought to bear. This pressure which moves or tends to move, electricity, is called electro-motive force or difference of potential. The unit of the electro-motive-force is the volt.

The unit of resistance is the ohm, which is the amount of resistance offered to the passage of an electric current by a column of mercury 106.3 centimeters long and one square millimeter in cross section measured at the temperature of melting ice.

One million ohms are called a meg-ohm, and a one-millionth ohm is called a michrom.

Now, whenever a current is flowing through any circuit having a resistance equal to that of the column of mercury just spoken of, that is the resistance of one ohm, and the pressure that is causing the flow of current equals one volt, then the current will flow through this circuit with an intensity of one ampere. The ampere is the unit of intensity of current.

The relation between these three factors holds good throughout the entire science of electricity; it is clearly expressed by Ohm's law as follows:

The intensity of current in any circuit is directly proportional to the pressure, and inversely proportional to the resistance. That is to say, with pressure of constant value, the less the resistance, the greater will be the intensity of the current, and, likewise, the greater the resistance, the less will be the intensity of the current.

Bearing these relations in mind we can always find the third factor when the other two are known. A few formulas will, very likely, explain the subject more clearly. The different units are represented by symbols, as follows:

The volt, unit of electro-motive-force, by E; the ohm, unit of resistance, by R; the ampere, unit of intensity of current, by I.

Ohm's law expressed by formula, is: $I=E/R$; that is, the voltage divided by the resistance equals the current; also, if $I=E/R$, R will$=E/I$, and E must equal I times R.

A few examples will establish the correctness of these formulas. A sixteen candle-power incandescent lamp requires about

one-half an ampere of current when burning on a circuit the voltage of which is from 100 to 110 (let us take the former for simplicity of figures). What must be the resistance of the lamp so that the proper current flows through it?

Solution:

Since R=E/I, it follows that the resistance of the lamp must be 100 volts.

$$\frac{100 \text{ volts.}}{.5 \text{ amp.}}=200 \text{ ohms,}$$ which is approximately the case in practice,

Now, if the resistance of the lamp were given us, say 210 ohms, and the current flowing were known to be .5 ampere, what would be the required voltage?

Solution:

Since E=I×R, the voltage must be .5×210=105 volts. If the resistance were 190 and the voltage were 110 how much current would flow through our lamp?

Solution:

Since I=E/R, it follows that the current must be:

$$\frac{110 \text{ volts}}{190 \text{ ohms.}}\text{.58 amp. (nearly).}$$

The resistance of the various substances varies greatly, some having a very high, and others a comparatively low resistance. Substances are divided into two general classes, relative to electricity, namely: Conductors and Insulators; the latter are sometimes called Dielectrics.

Conductors are those substances which conduct current readily. All the metals are conductors. Table 1 gives a list of various metals and alloys in the order of their value as conductors, each one having a lower resistance than those below it.

Name of metal or alloy.	Per cent conductivity.
Silver, pure	100
Copper, pure	100
Copper, commercial	99
Gold, pure	78
Aluminum	63
Zinc	29.9
Brass, containing 35 per cent zinc	26.49
Iron	16.12
Tin, pure	15.45
Lead, pure	8.88
Nickel, pure	7.89
German silver, composed of 4 parts copper, 2 parts nickel; 1 part zinc	7.8

Insulators are those substances which greatly resist the flow of electricity. Below is a list of insulators commonly used, those

higher up in the list having a higher resistance than the ones lower down: flint glass, porcelain, paraffine, hard rubber, gutta-percha, mica, marble and slate.

There are numerous others; their value, however, is less than those listed. Dry air has a very high resistance, as also has water that is chemically pure. Wood, fiber, silk, wool and cotton are also extensively used. However, as they readily absorb moisture their use is restricted to dry places, since moisture greatly lowers their insulating quality. Most oils are good insulators.

The unit of electric energy is called the Watt, and is usually represented or abbreviated P. One thousand watts are called a kilowatt or K. W. To find the watts in any circuit multiply the voltage by the current, thus: Volts$\times$amperes=watts.

In the case of an incandescent lamp taking, say, half an amp. of current at 104 volts, how many watts does the lamp consume?

Solution:

Since the watts equal volts times current, the lamp takes $104 \times .5 = 52$ watts.

A watt equals $^1/_{746}$th of a horse power, therefore to find the horse-power expended in any circuit divide the watts by 746. If we are burning 250 16 candle-power incandescent lamps, each lamp consuming 52 watts, how many horse-power are required?

Solution:

Since there are 250 lamps, each taking 52 watts, we have: $250 \times 52 = 13000$ watts; and since 746 watts equal one horse-power, we have:

$$\frac{13000}{746} = 17.43 \text{ H. P. (nearly).}$$

When the voltage and the resistance of a circuit are known and we want to find the watts, we square the voltage and divide the result by the resistance, thus:

Solution:

$$\frac{\text{Volts} \times \text{volts}}{\text{ohms}} = \text{watts, or } \frac{E^2}{R} = P.$$

Suppose we have a circuit whose resistance is 20 ohms, the voltage being 112, what do the watts equal?

Solution:

Since the watts equal the quotient of the square of the voltage divided by the resistance, we have:

$$\frac{112 \times 112}{20} = \frac{12544}{20} = 627.2 \text{ watts.}$$

When the current and resistance are given, the watts are found by multiplying the resistance by the square of the current, thus: amp. X amp. X ohms= watts, or $I^2 \times R = P$.

If the resistance of a circuit be 40 ohms and the current is 15 amperes what do the watts equal?

Solution:

Since the watts equal the current squared times the resistance, we have:

$15 \times 15 \times 40 = 9000$ watts; and since 1000 watts=one K. W.. (kilowatt) we have

$$\frac{9000}{1000} = 9 \text{ K. W.}$$

One K. W. equals, approximately, one and one-third H. P., and conversely, one H. P., equals three-fourths of one K. W.

As already stated, all substances resist the flow of current in a greater or less degree. From Table 1 we see that the conductivity of copper is very high, hence its resistance must be very low, the meaning of the two terms being the opposite of one another. Its conductivity is very little below that of silver, while its price is very much lower. It has by far the highest conductivity of any of the base metals and is therefore used very extensively in electric construction.

Since resistance is an inherent property of all substances we can readily understand that a bar of any material and a cross-section of say 1 square inch will have less resistance than a bar of the same length and material having a cross-section of only half an inch, as the path offered by the first bar is much larger than that of the smaller bar. Just the same as a pipe of 2 inches diameter will discharge more water under any given pressure; the same is true of an electric conductor. From the foregoing it follows that the resistance of a conductor increases directly as its length and inversely as its cross-section, *i. e.*, the longer a wire of given size the greater its resistance, and the shorter the wire the less the resistance. Also the larger the wire of given length the less the resistance, and the smaller the wire, of same length, the greater the resistance.

In electrical work the cross-section or area of wire is figured in circular mils, abbreviated C. M. or c. m. A mil is a one-thousandth part of an inch, and circular mil is one mil squared. A wire having a diameter of one-thousandth of an inch has an area of one circular mil; a wire having a diameter of, say $^{12}/_{1000}$ of an inch has an area of $12 \times 12 = 144$ c. m., since c. m.=the square of the diameter in thousandths of an inch. It should be noticed that in squaring the fraction which expresses the diameter, the numerator is the only factor considered, and it is taken as if it were a whole

number. A wire having a diameter of $^{125}/_{1000}$ of an inch would have an area of $125 \times 125 = 15625$ c. m. Conversely, if we know the cross-section of a wire in c. m., we can find its diameter by extracting the square root of its cross section. For instance, a certain wire is known to have an area of 211600 c. m., what is its diameter?

Solution:

Since the c. m. equals the diameter squared, the square root of the c. m. must equal the diameter; hence $\sqrt{211600} = 460$.

The resistance of one mil-foot of copper is app. 10.8 ohms. It is a trifle less, but for practical calculations this number answers very well. A mil-foot is the length of a wire one foot long having an area of 1 circular mil. Since we know the resistance of a mil-foot of copper wire we can easily figure just how much pressure or e. m. f. will be necessary to force a stated current through a copper wire of any length or cross-section. Remembering that the voltage equals the current times the resistance, we multiply the number of amperes we want by the length of the wire in feet; that would give us the voltage needed if the area of the wire were one c. m. We now divide that result by the area of the wire (circular mils) to be used and the quotient will be the voltage required.

TABLE II.

Gauge Number.	Area C. M	Amperes Weatherpr'f Wire (Open Work)	Amperes Rubber Covered Wire Concealed (Work.)	Ohms per 1,000 feet.	Pounds per 1,000 feet Insulated (Approximate.)
18	1,624	5	3	6.388	18
17	2,048	6	4	5.066	21
16	2,583	8	6	4.0176	25
15	3,257	10	8	3.186	31
14	4,106	16	12	2.5266	38
13	5,178	19	14	2.0037	43
12	6,530	23	17	1.589	48
11	8,234	27	21	1.2602	64
10	10,380	32	24	.99948	80
9	13,090	39	29	.79242	97
8	16,510	46	33	.62849	116
7	20,820	56	39	.49845	138
6	26,250	65	46	.39528	166
5	33,100	77	54	.31346	196
4	41,740	92	65	.24858	228
3	52,630	110	76	.19714	265
2	66,370	131	90	.15633	296
1	83,690	156	107	.12398	329
0	105,600	185	127	.09827	421
00	133,100	220	150	.07797	528
000	167,800	262	177	.06134	643
0000	211,600	312	218	.04904	815

Table II. gives a list of sizes of wire showing the gauge numbers, area in c. m., resistance and safe carrying capacity in amperes. The numbers are those of the B. & S. (Brown and Sharpe) gauge, which is the one in general use. The resistances given are for wire at a temperature of about 70 degrees F. The resistance of all metals increases with a rise in temperature. The percentage of change of resistance for a change of temperature of one degree is called the temperature coefficient. For ordinary calculations this need not be considered however, the temperature coefficient of copper being only .002156 ohm for one Fahrenheit degree. The resistance of carbon and non-metallic substances in general increases with a fall in temperature. If we know the available voltage, the amperes, and the length of the wire and want to find what size wire we must use in order that the available voltage will not cause an excessive flow of current, we multiply the length in feet of our wire by the amperes, and that product by 10.8 (the resistance of a mil-foot of copper) and divide the last product by the voltage; the quotient will be the required area in c. m. Also, if we want to find the current that will flow through a certain size wire of given length with given voltage we multiply the length of the wire by 10.8 and divide this product into the product of the area in c. m. of the wire times the voltage; the result will be the number of amperes. A few examples are given:

What voltage is required to force 10 amperes through a No. 8 wire 2500 feet long?

Solution:

$$\text{Since } \frac{\text{length} \times 10.8 \times \text{amperes}}{\text{area in c. m.}} = \text{volts, we have:}$$

$$\frac{2500 \times 10.8 \times 10}{16510} = 16.35 + \text{volts}$$

The c. m. of wires can be obtained by referring to Table 2.

What size wire must be used if we have an available voltage of 15, the current required being 4 amperes and the length of the wire being 1800 feet?

Solution:

$$\text{Since } \frac{\text{length of wire} \times \text{amp.} \times 10.8}{\text{volts}} \text{ equals the area of our wire}$$

$$\text{we have: } \frac{1800 \times 4 \times 10.8}{15} \text{ equals } 5184 \text{ c. m.}$$

From the table we see that the nearest wire size is No. 13, the area of which is 5178 c. m.

How much current will flow through 1200 feet of No. 16 wire when the pressure is 16.3 volts?

Solution:

$$\text{Since } \frac{\text{volts} \times \text{c. m.}}{\text{length} \times 10.8} = \text{amperes,}$$

$$\text{we have } \frac{16.3 \times 2583}{1200 \times 10.8} = \frac{42102.9}{12960} = 3.25 \text{ amp. (nearly)}$$

The calculation of wire sizes is very important in electric construction work, and will be taken up at greater length farther on.

In order to transmit electricity from one point to another it requires two paths; one, through which the current flows from the source to the point where it is wanted, the other path serving as a return for the current, after the latter has performed its work, to the source from which it started. Should the connection be broken at any point or points the circuit is said to be open,

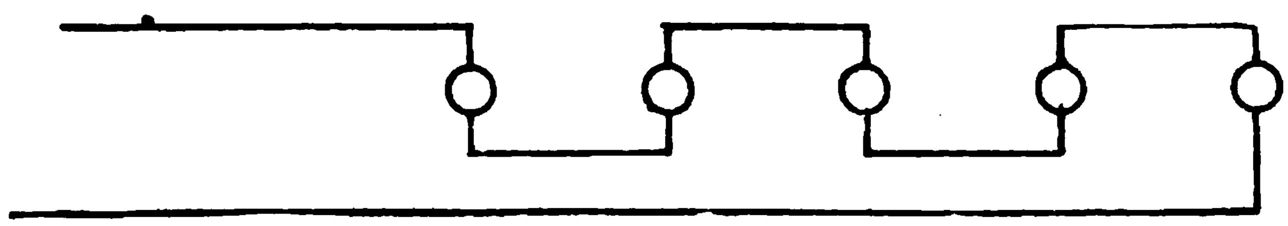


FIG. 1.

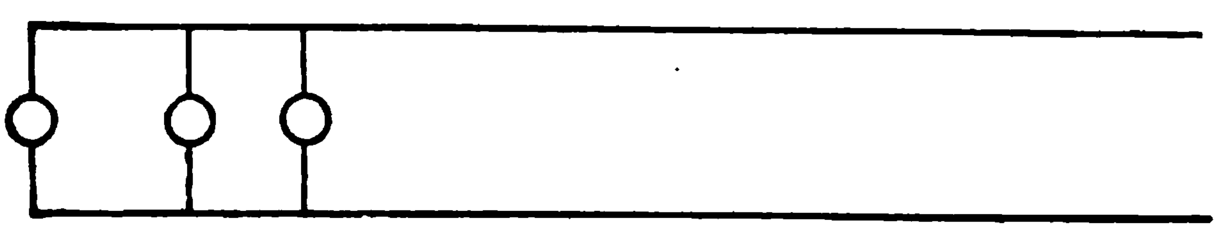


FIG. 2.

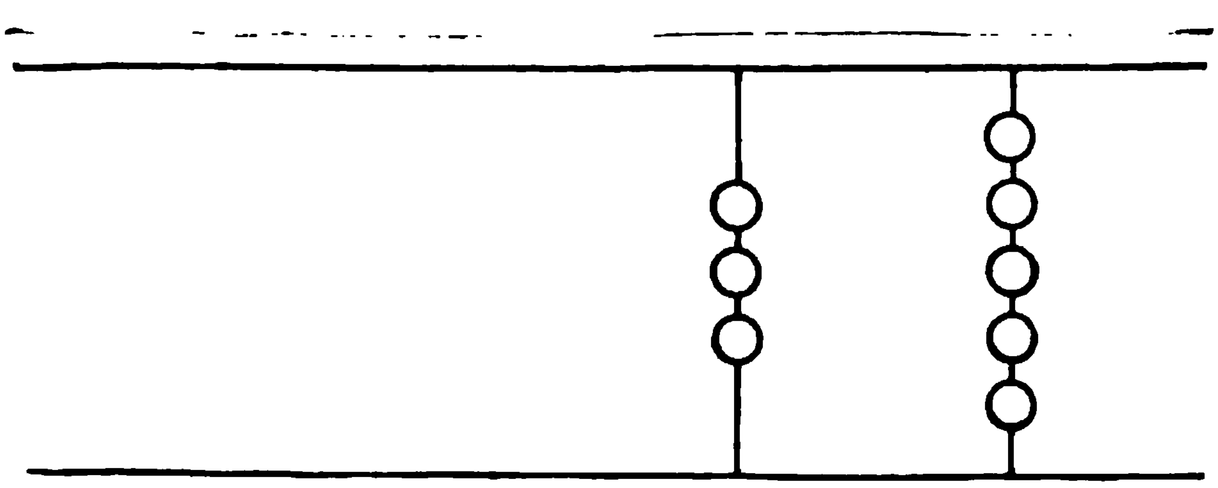


FIG. 3.

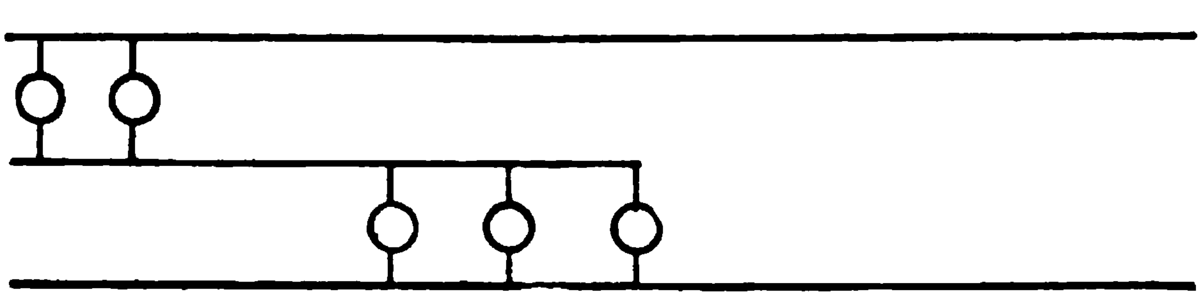


FIG. 4.

and, in such a case, no current can flow. It makes no difference whether we open the path over which the current flows out, or the one through which it returns, the effect will be to interrupt the flow of current, and any lamps connected to such a circuit would not burn.

When two wires coming from an electric source are connected together through such a low resistance that the resultant flow of current is excessive they are said to be short-circuited.

Electric apparatus and devices can be connected up in four different ways, viz: series, parallel or multiple-arc, multiple-series and series-multiple. Figures 1, 2, 3 and 4 show incandescent lamps connected in the four ways named. In the series connection one end of the first lamp is connected to the source of current and the other end is connected to one end of the next lamp, the other end of which is connected to the third lamp, and so on through the whole series, the last lamp being connected to the wire returning to the source. It is evident that the current strength must be the same at all points of the series, since the current through one of the lamps must go through all of them. The resistance of the five lamps in series would be just five times the resistance of one lamp, assuming all to have equal resistance, hence the current that would flow through them at any given voltage would only be one-fifth of what it would be if only one lamp were connected to the two outside wires, which we will call the mains. Thus, if each of our lamps has a resistance of 200 ohms, the five in series would have a resistance of $200 \times 5 = 1000$ ohms, and if the voltage of our mains were 500 volts the current flowing through our lamps would be, according to Ohm's law:

$$\frac{500 \text{ volts}}{1000 \text{ ohms}} = .5 \text{ amp.}$$

If the resistance of the lamps should not be the same it would not be correct to multiply the resistance of one by their number; to find the combined resistance in such a case we add the individual resistance of all of them together. Supposing one lamp to have a resistance of 200, one 150, another 210, the fourth 180 and the fifth 190, the combined resistance would be $200 + 150 + 210 + 180 + 190 = 930$ ohms. Evidently if one of the lamps burns out, or becomes disconnected, the circuit will thereby be opened and no current can flow and all five lamps will go out, unless some means of closing the circuit is provided. Figure 2 shows three lamps connected in parellel or multiple-arc, or simply multiple; one side of each lamp being connected to one of the mains, the other side of the lamp to the other main. The current flowing through any one lamp will depend, with a given

voltage at the mains, entirely upon the resistance of the lamp, each of them being independent of the others; and one or more of them burning out will not affect the burning of the others. All incandescent, and most arc lamps for indoor service, are connected in multiple principally because in that case each lamp is independent of the rest. The combined resistance of the three lamps, or their joint resistance, as it is called, is equal to the resistance of one divided by the number of lamps, if they all have the same resistance; thus if they each have a resistance of 210 ohms their joint resistance is $^{210}/_{3}=71$ ohms. If they differ in resistance their joint resistance is found by multiplying the three resistances together and dividing that product by the sum of the products of the first $\times$ the second, plus the first $\times$ the third plus the second $\times$ the third. For instance, if one lamp has a resistance of 200 ohms, one 210 ohms and the third 180 ohms what is their joint resistance?

Solution:

Since the joint resistance equals the continued product of the first, second and third resistances divided by the sum of the first by the second, plus the first by the third, plus the second by the third, we have:

$$\frac{200\times210\times180}{(200\times210)+(200\times180)+(210\times180)}=\frac{7560000}{42000+36000+37800}=\frac{7560000}{115800}=65.285 \text{ ohms. (nearly)}$$

Motors are also connected in multiple or parallel. The third method shown by Figure 3 is the multiple series method and consists of connecting a series of any number of lamps or other devices in parallel across the mains; this is done when the resistance of one lamp would not be high enough to prevent an excess of current when cut directly across the line, and is done principally in street railway cars, power-houses, car-barns and sheds, etc., where the voltage is 500 volts or more. No lamps being made for such a high voltage, five 100 or 110 volt lamps are connected together in series and this series is then connected across the two sides of the supply circuit. Of course, one lamp could be burned alone even on a 500 volt circuit by cutting a resistance in circuit with the lamp; as this would be an expenditure of energy which gives no useful return it is clearly a waste, and this is, therefore, never resorted to except for special purposes. The fourth, or series-multiple method is very seldom used, except occasionally to control the speed of small motors, in which case a number of lamps connected in multiple are cut in series with the armature of the motor; by cutting in a greater or less number of lamps, more or less current can flow, and the speed will vary accordingly. When only one lamp is burning the motor will be at the slowest speed; each additional lamp cut in will increase

the speed, as the more lamps are cut in, they being in multiple, the less will their joint resistance be, hence the more current will flow.

CHAPTER II.

THE RELATIONS BETWEEN MAGNETISM AND ELECTRICITY.

The relations between electricity and magnetism are very close, and their effects, one upon the other, will always be the same under similar conditions. Upon these relations, and the mutual force that they exert upon one another, depends the operation of all dynamo-electric machines. They are the foundation upon which electrical science rests.

Magnetism is inseparable from electricity, since we have no flow of the latter without producing the former. However, the presence of magnetism does not necessarily imply the presence of an electric current.

A magnet is a piece of any substance which is capable of attracting other magnetic substances such as iron or steel. A magnet, also, if it is free to move, will place itself so that one of its ends, called the N (north) pole, will point to the geographical north of the earth, and the other, called the S (south) pole, toward the south. The earth itself is a magnet, magnetic lines of force issuing from its north pole, traveling through the surrounding medium and entering the earth again at its south pole. The same is true of all magnets; magnetic lines of force or magnetic flux emanating from one end, traversing the surrounding medium and entering the magnet again at its other end. These magnetic lines have no real existence; their presence is spoken of only to aid us in establishing a clear idea and understanding of magnetic phenomena.

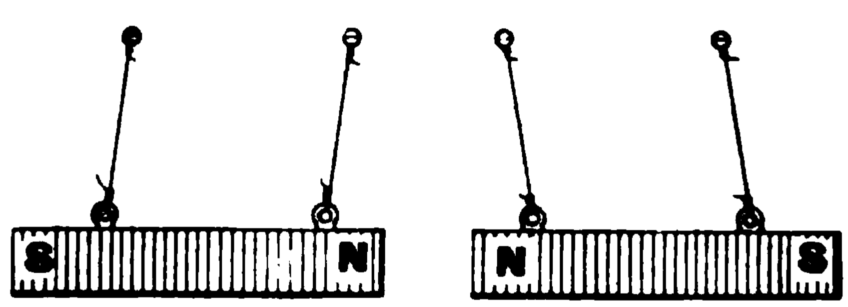


FIG. 5.

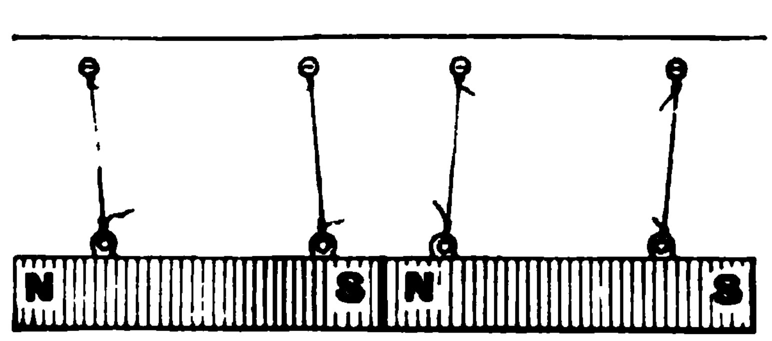


FIG. 6.

One of the laws of magnetism is that no magnet can exist with but one pole; there must always be two; one, the N (north) pole from which the lines of force are said to issue, and the S (south) pole, or the end where the lines enter the magnet.

Magnets will either attract or repel one another, depending on the direction of the lines of force at the two ends, or as we say, upon their polarity. If we let the N pole of two magnets approach each other repulsion will take place, whereas, if we let a N pole of a magnet approach the S pole of another magnet attraction will take place. See Figures 5 and 6 where two magnets are suspended, each by two strings so that gravity would cause the magnets to hang about a quarter of an inch from one another. The mutual repulsion between the like poles of the magnets in Figure 5, forces them farther apart, while in Figure 6, the magnets are drawn towards one another by the mutual attraction between the unlike poles. The same thing would happen in each case if the magnets were suspended side by side instead of being end to end. From the foregoing we deduct another law of

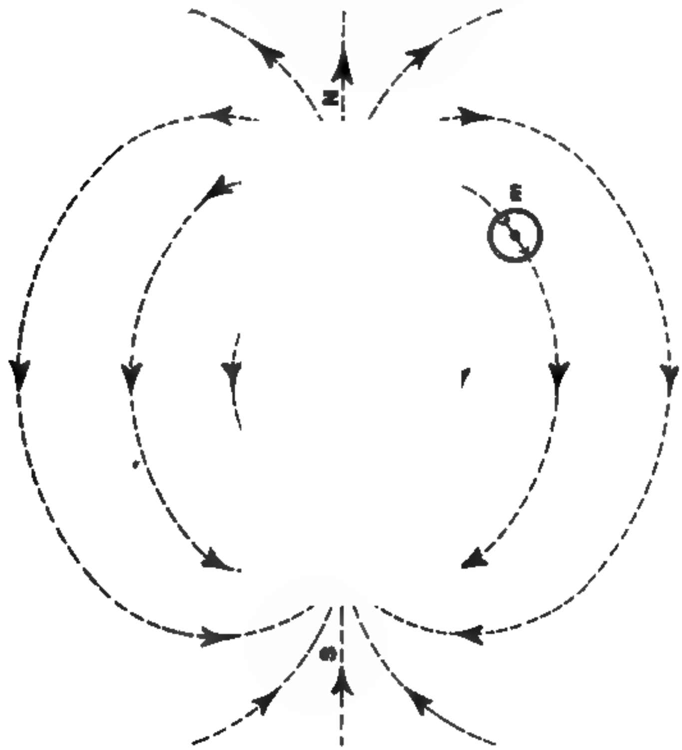


FIG. 7.

magnetism, namely, that like poles repel, and unlike poles attract one another.

From Figure 7 we see that while the flux travels from the N pole of the magnet to its S pole in the surrounding medium, yet, within the magnet itself, the direction of the flux is from the S to the N pole.

FIG. 8.

Magnetic lines can never cross one another. If two magnets are placed with their like poles near one another their respective fluxes will be crowded out of their original position and the position they assume will depend upon the relative strengths of the two magnets. See Figure 8.

Figure 9 shows the path of the magnetic lines when two like poles are near each other; were the two placed together a consequent pole would be formed at the juncture, as shown in Figure 10.

When magnets are placed with unlike ends together the path of the flux would be just the same as if it were one magnet as shown in Figure 11. In these illustrations the lines of force have been shown in the plane of the paper only; it must be understood however, that they travel in equal strength in every direction.

By means of a compass one can readily tell which end of a magnet is north or which is south. The end which attracts the N pole of the compass is the S pole of a magnet, since unlike poles attract one another; likewise the N pole of a magnet will repel the N pole of the compass. A magnet exhibits magnetism only at and near its ends; at and near the center very little being noticeable.

The space surrounding a magnet is called a magnetic field and a compass placed in such a space will always point in the same direction.

There is no substance known which will insulate for magnetism, that is confine it to any particular path as can be done with electricity or any liquid. We can, however, provide a path through which a greater portion of the lines issuing from a magnet will pass. All substances offer some resistance to the passage of magnetic flux. This property is called magnetic reluctance,; air has the greatest reluctance of any known substance and soft iron the least. Magnetic substances, of which iron and steel are

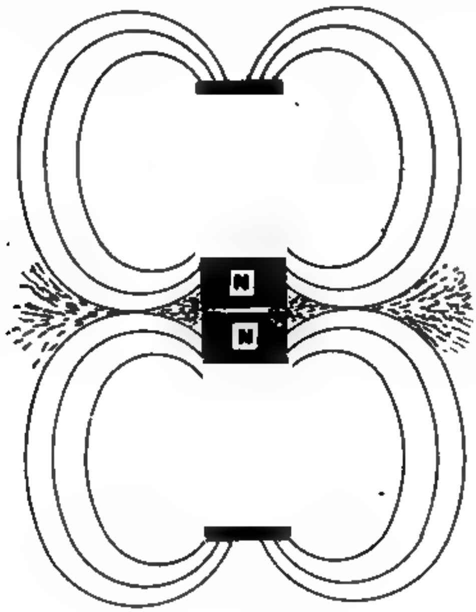


FIG. 9.

FIG. 10.

the main ones, afford a very easy path for the passage of magnetic flux. This property, of readily permitting the passage of magnetism, is called permeability. The permeability of very soft iron is nearly 2000 times that of air.

If the end of a bar of iron be put in contact with the end of a magnet the free end of the iron will have the same polarity that the end of the magnet to which the iron is attached has, and there will be very little free magnetism at the point of juncture. The same would be true in each case if more pieces of iron were added to the one already joined. Permanent magnets are those which retain their magnetism a long time. These are usually made in bar or in horseshoe form. They are made of steel shaped to the required form, hardened and then magnetized. The latter can be done either by placing the ends of the piece to be magnetized against the poles of some other magnet, or, which is better, by causing an electric current to flow through a coil of wire wound around the piece.

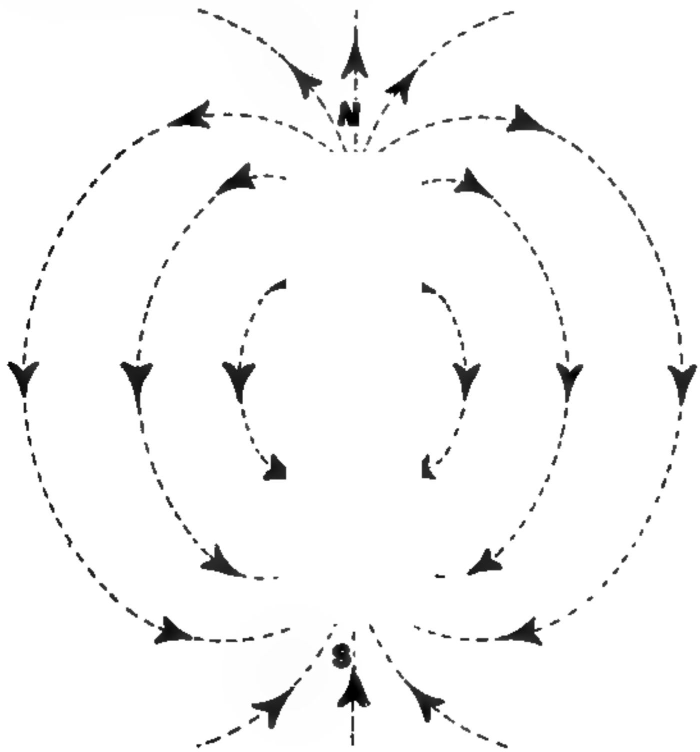


FIG. 11.

As has been already stated, magnetism is inseparable from electricity, since whenever an electric current is flowing over a wire the latter will be surrounded by magnetic flux throughout its entire length. This flux travels in circular paths around the wire and its strength is proportional to the strength of the current in the wire. The direction in which the lines circulate depends upon the direction of the current in the wire. See Figure 12.

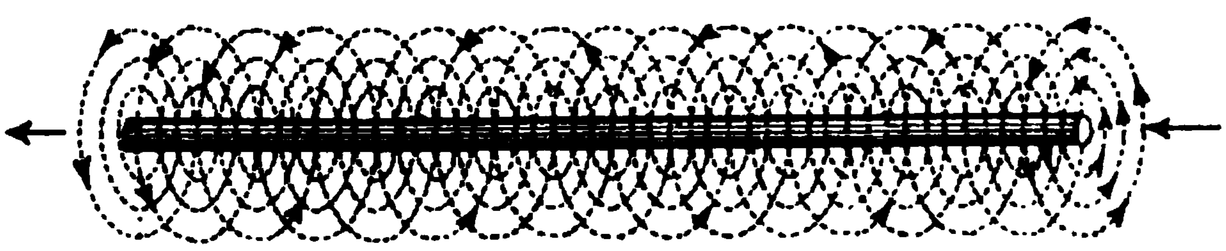
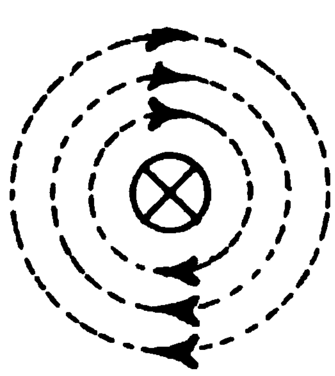


FIG. 12.



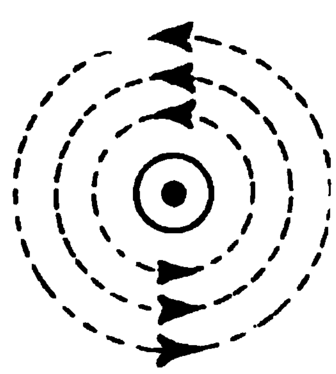


FIG. 13. FIG. 14.

The direction of the current is indicated by the arrow at one end of the wire and that of the magnetic flux by the arrow heads on the circles around the wire. In Figure 13 the current is flowing downwards or from us, that is piercing the paper, as is represented by the cross in the conductor, which let us consider as the retreating tail of an arrow, while the dot in the center of Figure 14 represents the point of an advancing arrow, indicating that the

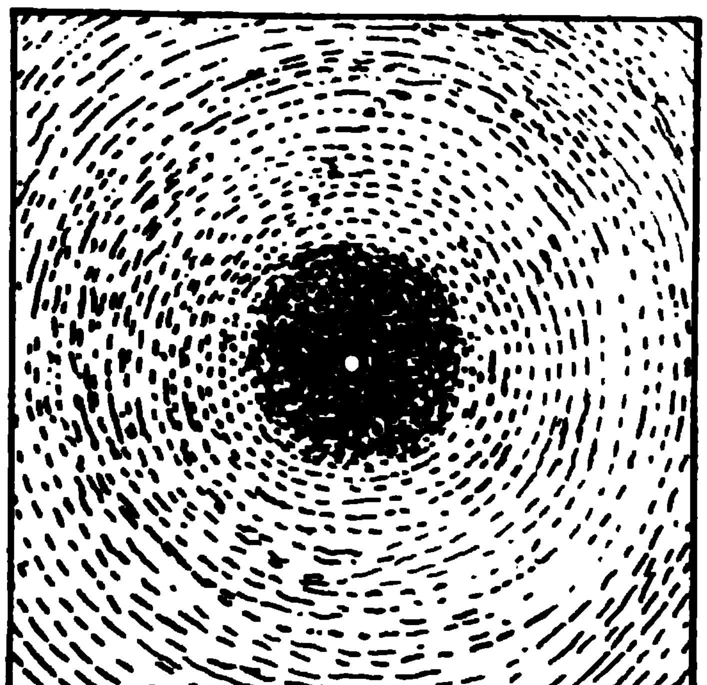


FIG. 15.

current is flowing upwards or towards us. The direction of the magnetic flux or the lines of force in each case is indicated by the arrowheads upon the circles surrounding the conductor. The existence of this magnetic flux can be readily demonstrated by letting a wire pass vertically through a card and placing a quantity of small iron filings upon the latter, when, if we cause a current to flow in the wire and gently tapping the card the filings will arrange themselves about the conductor as shown in Figure 15.

The greater part of the filings will remain near the center showing that the magnetism is stronger near the wire than at a distance from it. This magnetism is due entirely to the effect of the flow of current in the wire; were the experiment with the filings tried when no current is flowing in the wire the filings would not be affected, showing conclusively that no magnetic flux is present.

If we place a compass over a wire running in a northerly and southerly direction and another one under the wire, as shown in Figure 16, both needles will lie parallel to the wire. As soon,

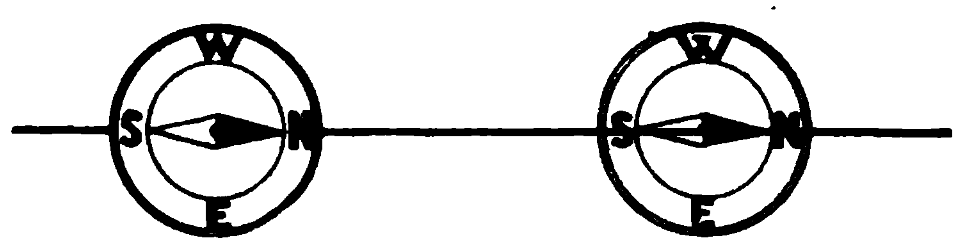


FIG. 16.

however, as we cause a current to flow through the wire the needles will be deflected into positions at right angles thereto, and, also, the two needles will move in an opposite direction to each other. Moreover they will only remain in this position while current is flowing, coming back to their original position when the flow of current stops. The direction in which they are deflected always bears the same relation to the direction of the current that produces the deflection. This relation is shown in Figure 17, where the current is flowing from left to right as indicated by the arrow which also represents the wire.

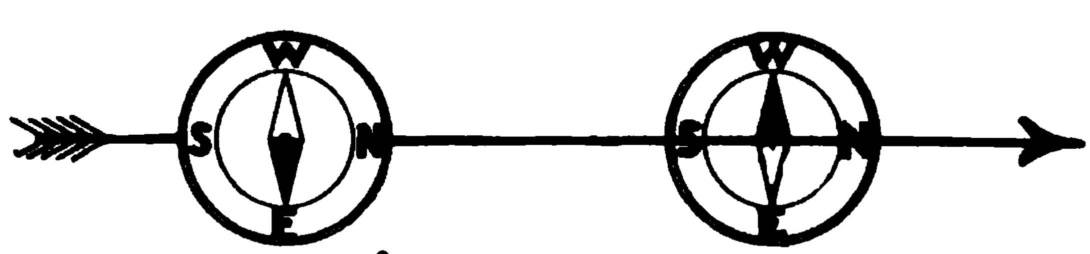


FIG. 17.

When the current is flowing from south to north, as in the figure, the needle over the wire will be deflected so that its north-seeking or N pole will point towards the east, and the N pole of the needle under the wire will point west. Reversing the direction of the current will cause a reversal of these deflections as

shown by Figure 18. The reason why the needle over the wire is deflected opposite to the one under the wire is, that since the magnetic forces are acting in a circular direction, with the wire as a center, if their direction is from left to right above the wire, their direction will be from right to left below the wire, as a reference to Figure 19 will show, which represents a wheel, whose direction of rotation is indicated by curved arrows.

What goes up on one side must come down on the other. Therefore the forces acting above the wire, although acting in the

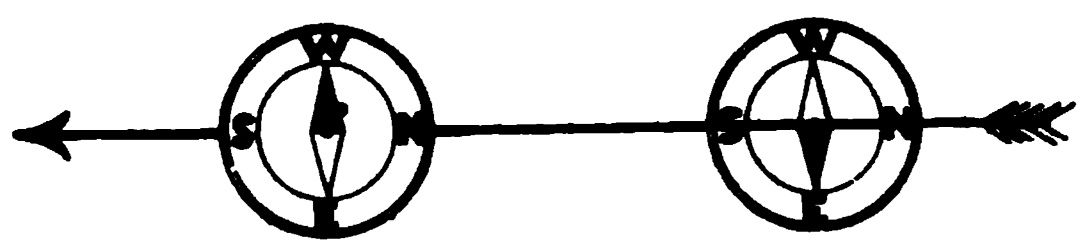


FIG. 18.

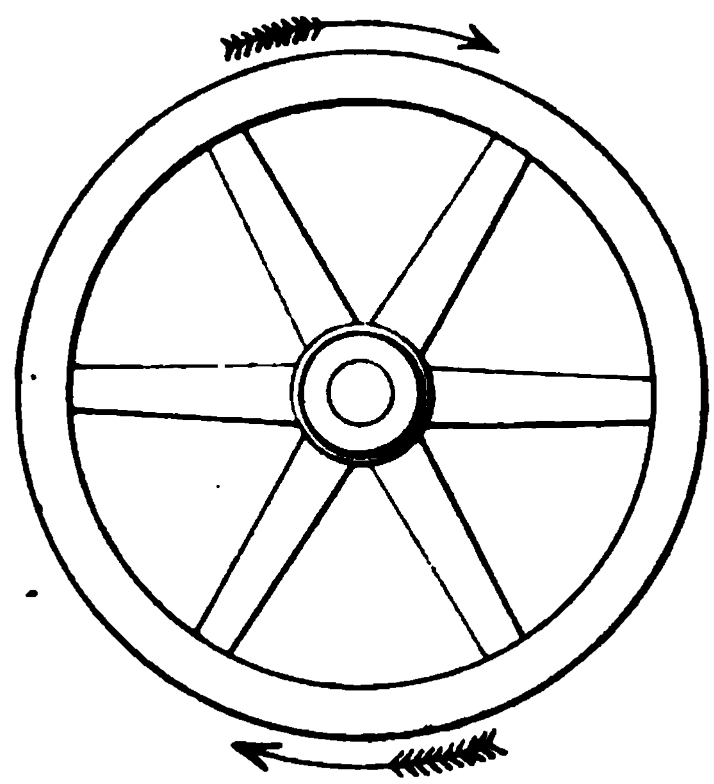


FIG. 19.

same continuous path will, by reason of such continuous flow, act in an opposite direction to the forces acting under the wire. Their mutual effect, however, is not to neutralize or destroy each other, as might at first sight be supposed, but on the contrary, they aid one another.

Let us see if we can prove it. We will bend our wire into a loop and place a compass within it so that part of the loop shall be under and part of it over the needle; shift the loop until it is parallel to the needle; upon causing a current to flow through our loop the needle will be deflected as in the case of the straight conductor. The force exerted upon the needle, however, will now be twice as great as in the former case, provided the strength of the current has remained the same. Figure 21 shows the reason for this, since it shows that the direction of the magnetic forces

within the loop are both acting from right to left, hence acting in the same direction. By increasing the number of turns of the loop we increase the strength of the magnet flux in a corresponding degree for a given strength of current. Let us make a coil of wire, Figure 22, and cause a current to flow through it in the direction indicated by the head and tail of an arrow at the ends. The direction of the resultant magnetic flux will be as shown by the arrow passing through the coil. If we take a bar of iron and hold one of its ends just within one end of the coil it will, if it is not restrained, be drawn fully into the coil. The violence of the

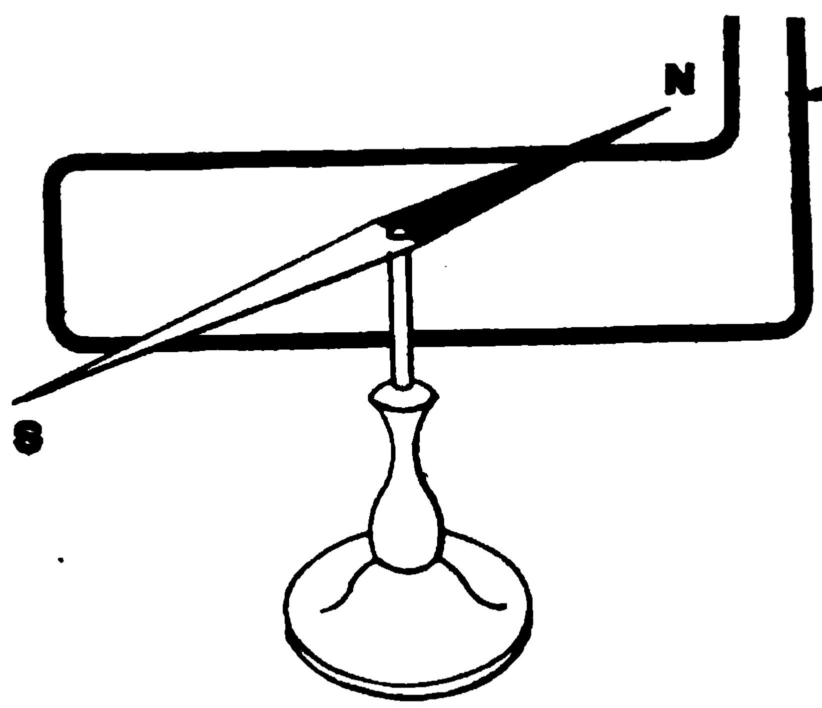


FIG. 20.

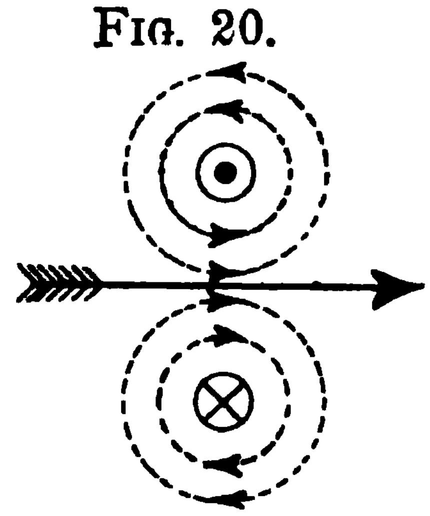


FIG. 21.

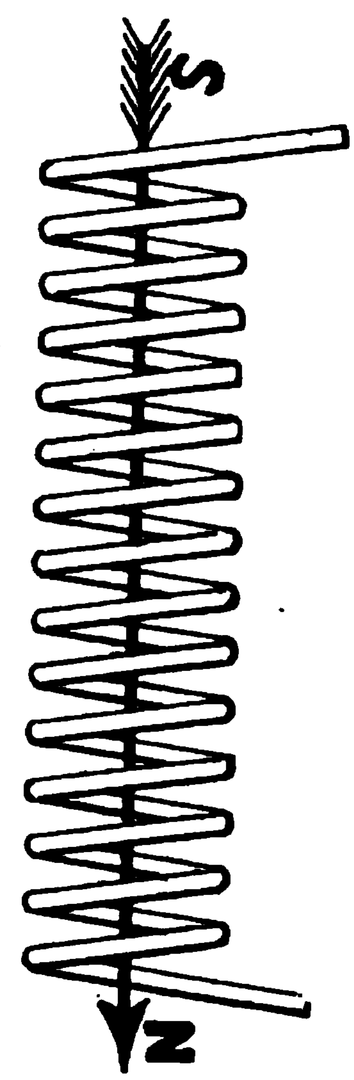


FIG. 22.

pull will depend, with given current strength, directly upon the number of turns in the coil, or with a given number of turns, upon the strength of the current flowing through the coil. Moreover, if the current travels along the coil from left to right and circulates around the successive turns in a clock-wise direction the right hand end will have N-polarity. If the current were flowing in the same direction along the coil, that is from the left to the right hand end, but were circulating in the loops themselves in an opposite or counter-clock-wise direction, the right hand end would have S polarity. We need not wind all of our turns in one layer but may wind them in a number of layers, one upon the other and we will obtain the same result.

As soon as the current ceases to flow through the coil surrounding our bar, the latter loses its magnetism immediately and can be withdrawn from the coil readily. If we now reverse the direction of the current through the coil and hold the end of the bar within the end of the coil the bar will be drawn into the coil as before and exhibit the same magnetic properties that it did in the first instance, except that its polarity will be reversed owing to the reversal of the current in the coil.

Such magnets are called electro-magnets. Although they lose their magnetism as soon as the current through their exciting coil stops, they retain a very small amount of it nevertheless. This is called Residual Magnetism.

Having seen how electricity is productive of magnetism; let us now see how, by means of the latter, we can produce a flow of electricity.

Right here let me say, however, that the talk about generating or making electricity is all wrong. Electricity is ever present and always in the same quantity. We might as well, in speaking of a pump, for instance, say the pump makes the water, which, as every body knows, it does not; it just exerts a pressure upon the water, which pressure causes the water to flow. Likewise with electrircity. All that is necessary to produce a flow of the latter is to generate an electro-motive-force; that is, to put it under pressure, and it will readily flow if a path is provided for it. In a number of ways it can be compared with water or air; it requires a force to cause a movement of either. Either can be confined to certain paths and the flow of each is always from a higher to a lower level.

If we take a coil of wire, Figure 23, and insert a magnet into it right quick an e. m. f. will be induced in the coil which will

Fig. 23.

deflect the compass needle as shown. This e. m. f. will only exist while the magnet is moving; when the movement of the magnet stops the needle will return to its original position. Having lowered our magnet into the coil let us withdraw it; we find that on doing so the needle will again be deflected, but in the opposite direction to the former one, showing that the current flowed in the opposite direction.

Now, how are these e. m. f.'s produced? Whenever a conductor is placed in a magnetic field the magnetic flux in the path of which the conductor lies must thread through the conductor. If we move the latter so that it will come into the path of a greater number of lines then an e. m. f. will be induced in the conductor because there has been a change in the number of lines through it; the same will be the case if we move it from a position where it is in the path of a maximum amount of flux, to a position where the flux is less.

As the magnet enters our coil, the wires of the latter come into the path of the flux surrounding the former, thus changing the amount of flux through the coil from zero to maximum. When the latter state is reached, that is when the magnet is all the way in the coil, no more e. m. f. will be induced until we withdraw the magnet. As the direction of the induced e. m. f.'s depends on the direction of cutting the flux or lines of force by the conductor, we can readily understand why withdrawing the magnet produces an e. m. f. in opposition to that induced by inserting the magnet, since the direction of cutting the lines of force has been reversed.

CHAPTER III.

ELECTRO-MAGNETS.

Most magnets, one might almost say all magnets used in dynamo-electric machinery are electro-magnets. The ease with which their strength can be varied, the constant value of their field for given amount of exciting current, the much higher degree of magnetization they are susceptible of, compared with permanent magnets, makes them far superior to the latter. Hence they are used to a much greater extent. Their strength, that is the number of lines of force or the amount of magnetic flux issuing from their poles is always dependent on three factors, namely: Number of turns in their exciting coil or coils, intensity of current flowing therein and the reluctance of the magnetic circuit.

Magnetic flux acts almost the same as electricity, inasmuch as it requires the action of a force to cause it to circulate. This force which causes a flow of magnetism is called magneto-motive-force, usually abbreviated m. m. f. or M. M. F.; the unit of m. m. f. is the Gilbert. M. m. f. corresponds to e. m. f. in elec-

tricity, being the pressure which produces the flow. As electric circuits have resistance, so also have magnetic circuits. In the latter case, however, it is called reluctance, being the resistance any substance offers to the passage of magnetic flux. The unit of reluctance is the Oersted, which is the reluctance of one cubic centimeter of vacuum. It is the opposite of permeability; substances possessing the former in a high degree possess the latter only in a very inferior degree and, conversely, substances having a low reluctance have a relatively high permeability, as, for instance, iron and steel. There is very little difference in the reluctance of the non-magnetic substances; wool, air, stone, fibre, cloth, rubber, etc., all have practically the same reluctance.

In the magnetic circuit the flux equals the gilberts divided by the oersteds; in other words, gilberts/oersteds=the maxwells, which latter term bears the same relation to magnetic circuits that the ampere bears to electric circuits. It is the unit of strength of magnetic flux or intensity. As in electricity $I=E/R$, $R=E/I$ and $E=I\times R$, so also in magnetism maxwells=gilberts/oersteds, oersteds=gilberts/maxwells and gilberts equals maxwells$\times$ oersteds.

As iron has a very low reluctance, it follows that with given amount of magnetizing current the strength of the flux will be much greater if the magnetic current is all of iron than it would be if it were only partly of iron or if it contained no iron at all. As in the case of an electric conductor the resistance increases directly as its length and inversely as its cross-section, so is it also with the magnetic circuit; with certain modifications, however, since we can not confine magnetism to any definite path as we can electricity, there being no known insulator for the former.

The rule holds good though, in general: If we double the cross-section of our magnetic circuit we halve its reluctance and if we halve its cross-section we double its reluctance; likewise, if we double its length we also double the reluctance, while if we halve the length we halve the reluctance. That is, assuming the substance of which the magnetic circuit consists to be the same in both cases. The reluctance of a magnetic circuit which is composed of air or some other non-magnetic substance can be greatly diminished by the insertion of iron even though the actual length thereof is increased; conversely, removing the iron will, although it may actually shorten the magnetic circuit, increase its reluctance.

The strength of any electro-magnet can be easily varied by varying the number of ampere-turns in the exciting coil. An ampere-turn is one complete turn of wire carrying one ampere of current, or any combination of number of amperes and number of turns which, when multiplied together equal one; two turns

each carrying half an ampere equal one ampere turn, since $2 \times \frac{1}{2} = 1$. A coil of 100 turns carrying 15 amperes is said to have 1500 ampere-turns, whereas if the same coil were carrying but one-fourth an ampere, it would have 25 ampere-turns, since number of turns multiplied by number of amperes equal the ampere-turns. In the first case we have $100 \times 15 = 1500$ and in the second case we have $100 \times \frac{1}{4} = 25$ ampere-turns. One ampere-turn will produce a m. m. f. of approximately, one and one-fourth gilberts. Hence the more ampere-turns the greater the m. m. f. and, with a magnetic circuit of given reluctance, the greater the intensity of the flux or the number of lines of force set up by this m. m. f. From the foregoing it follows that in order to vary the strength of a magnet all that is necessary is to vary the current through the exciting coil; the same result can also be obtained by winding the coil in sections and by cutting these sections in or out of circuit and thus change the number of effective turns. This is sometimes done; the first method, however, is the one commonly used.

The reluctance of non-magnetic substances is practically the same at all flux densities, while the reluctance of iron and steel increases with an increase of magnetic flux until a point is reached where no amount of additional magnetizing current will appreciably increase the magnetism. This point is called magnetic saturation, and when a magnet has reached this point it is said to be saturated. It is clearly a waste of energy to endeavor to force a magnet beyond the saturation point, as the only effect will be to heat the magnet.

Magnets can be divided into two general classes, viz.: Those which have great power for pulling armatures from a distance, called tractive magnets; second, those whose range of pull is limited but will support a heavy weight attached to their armature after the latter is in contact with the pole faces; these are called portative magnets. A notable instance of the use of these is in the Plate-Mill of the Illinois Steel Co.'s works at South Chicago. Where formerly the plates were hoisted by means of hooks and chains attached to the hook of a crane or conveyor, they are now

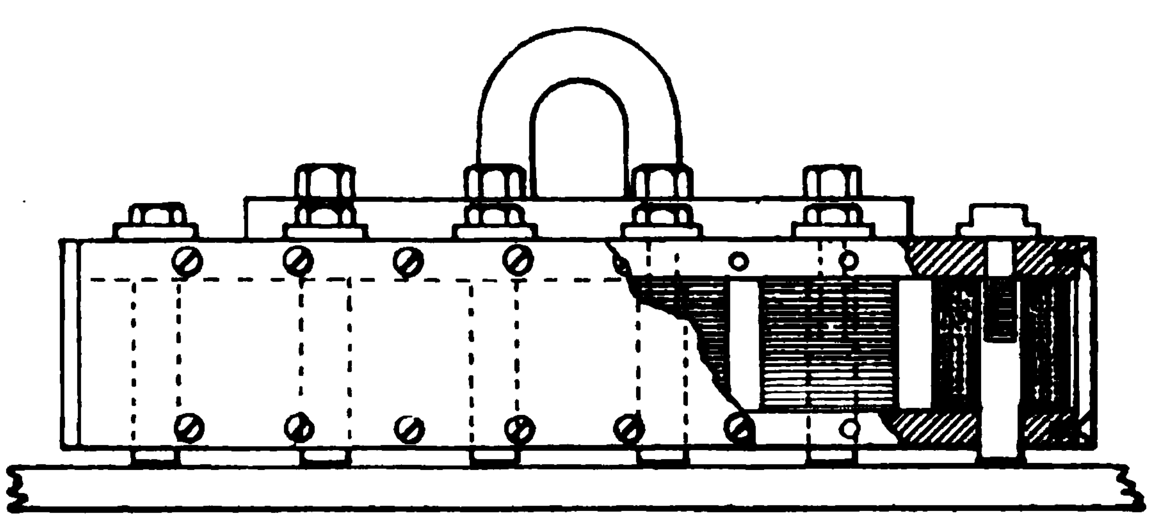


FIG. 24.

picked up by means of an electro-magnet attached to the crane or conveyor hook. The magnet is lowered down onto the plate that is to be hoisted; as soon as it is in the proper position on the plate the operator closes a switch, which permits current to flow through the coils of the magnet and then hoists up and the plate will come along. When the hoisted plate is over the place where it is wanted, the crane operator simply cuts off the magnetizing current and the plate drops. The plate forms the armature of the magnet, being in direct contact with the pole faces.

Figure 24 gives a view of one of these magnets.

FIG. 25.

Tractive magnets are of two kinds: Those acting rapidly and through a short space only, and those acting somewhat slower but through a greater distance. Examples of the former are the electric bell and the telegraph sounder; an example of the latter kind is the solenoid magnet, which consists of a coil of wire, the length of which is usually greater than its diameter, in which the armature or core can slide up and down readily. See Figures 25 and 26. They have a comparatively long range, and a strong pull. Figure 25 shows a simple solenoid with an iron plunger; this type is not near so effective as that shown by Figure 26, because the magnetic flux must return through the air from one pole of the core to the other, hence the magnetic circuit will have a high reluctance and, with the same amount of exciting current, can not have as high a degree of magnetization as the other, the magnetic circuit of which is composed entirely of iron, except when the plunger is down; and even with the plunger down the reluctance will not be near as great as that of Figure 26. The one shown in Figure 26 is the most effect-

ive of the three, but as the coil is entirely imbedded in iron, it will heat more for given current. As the plunger enters the coil the air-gap between the face of the plunger and the face of the magnet pole decreases, thus decreasing the reluctance and thereby increasing the pull or tractive effort of the magnet. The end of the plunger should be capped with a thin piece of some non-magnetic substance so that it will drop readily when the exciting current is shut off; were this not done the residual magnetism would very likely cause it to stick.

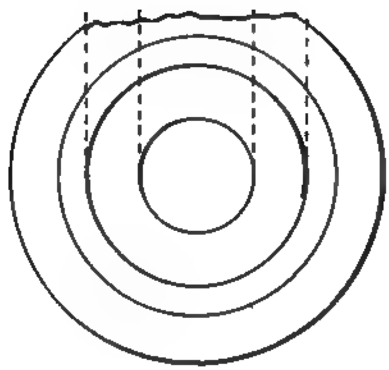


FIG. 26.

CHAPTER IV.

ELEMENTARY THEORY OF THE DYNAMO.

We have seen that when lines of force are cut by a conductor an e. m. f. is induced in that conductor. Let us now see how that is accomplished in the dynamo.

Figures 27 and 28 show a dynamo in its simplest form, viz.: a loop or coil of wire, L, mounted on a shaft between the poles of a magnet in such a position that the two sides of the loop are parallel to the faces of the magnet poles; therefore, revolving the coil will cut the flux that is passing between these poles at right angles. It is necessary that this be the case, since to generate an e. m. f., it is not sufficient to simply move a conductor in a magnetic field; the conductor must cut across the flux or lines of force at right angles thereto.

Figure 27 shows the loop in a position where the flux through the loop is zero, since all the flux is passing through the space within the loop as shown by Figure 27(a), which shows the loop with the N pole removed, the flux being represented on the face of the S pole by circles with crosses in them, which latter let us consider as the tails of retreating arrows, showing that the direction of the flux is downwards or piercing the paper. Figure 28

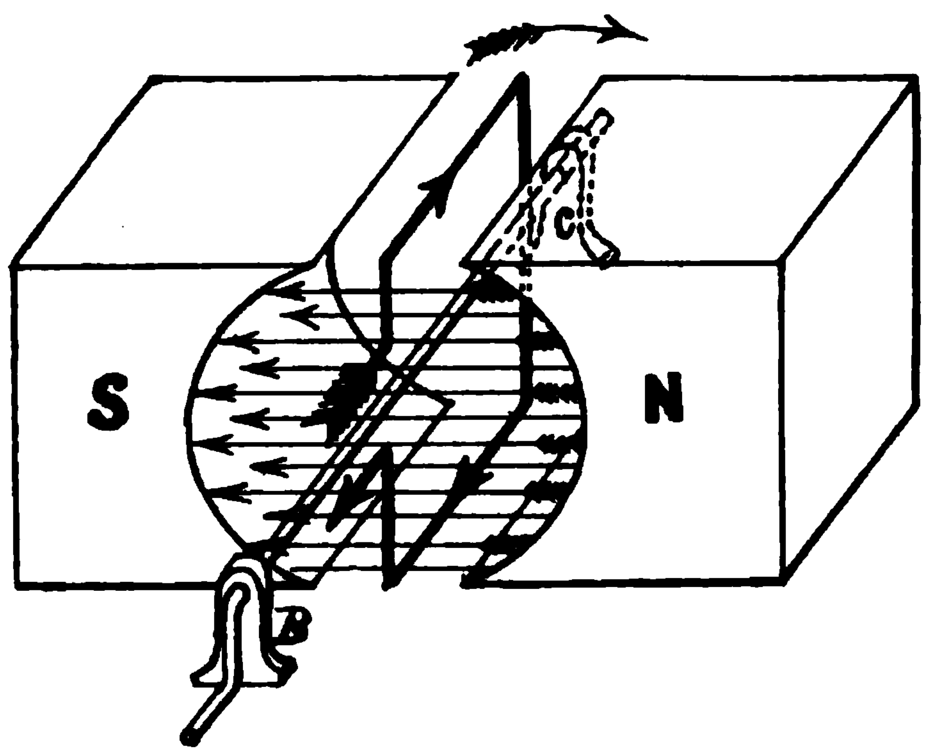


FIG. 27.

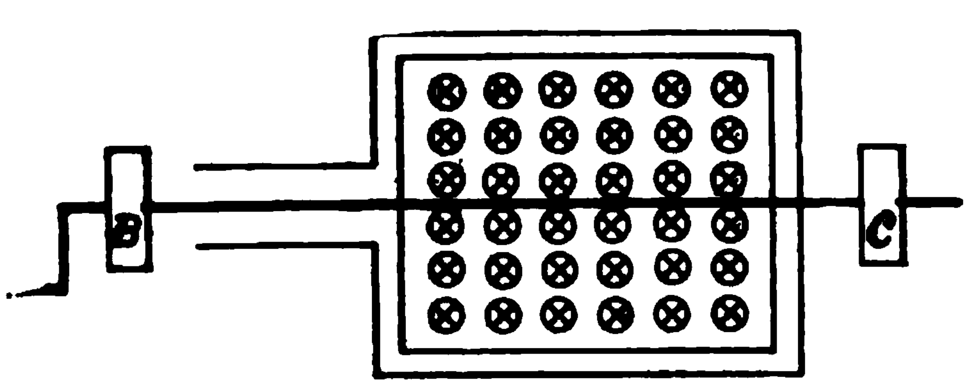


FIG. 27a

shows the loop in position where the amount of flux through it is maximum. The loop is mounted in bearings B and C and is fitted with a crank as shown. The blocks (marked N and S) on the sides of the loop are the poles of a magnet and the magnetic flux is represented by the arrows passing from pole to pole.

By turning the crank we can turn this loop in either direction. We will turn it through 180 degrees or one half a revolution; it will then occupy the position shown by Figure 28. Since by this motion the loop cut the magnetic flux an e. m. f. was set up therein and, had the ends of the coil been connected together current would have flown through it. Continuing the rotation through the next half revolution an e. m. f. will be set up which will be in an opposite direction to that set up by the first movement. From this it follows that the direction of the induced current depends on the direction in which the conductor moves across or through the magnetic flux and the direction of the latter. Cutting the flux

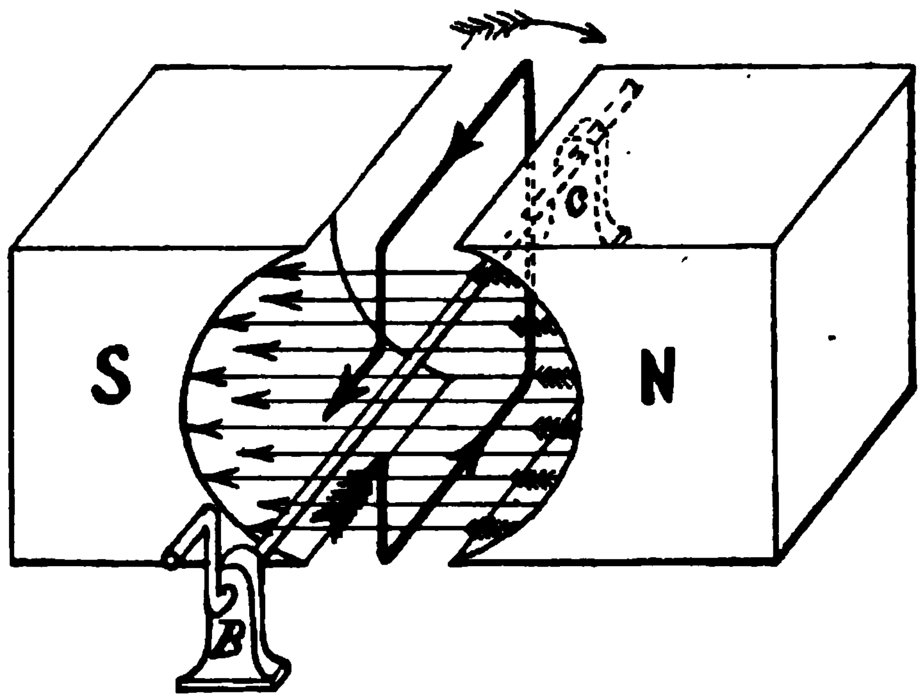


FIG. 28

from top to bottom will cause current to flow from the observer when the direction of the flux is from right to left, and toward the observer if the flux travels from left to right. Reversing either the direction of motion of the loop or the direction of the flux will reverse the direction of the induced e. m. f. Figures 27 and 28 show these relations; the N pole being on the right side, the flux must travel from right to left; the direction of rotation, as indicated by the curved arrow, being such that the right hand side of the loop moves downward, hence the direction of the e. m. f. will be outward, that is towards the front end as shown by the arrowhead on the loop. The direction of the current in the left hand side of the loop will be towards the rear end of the loop owing to the fact that it is cutting the flux in an opposite direction to that of the right hand side; the latter moving downwards and the former moving upwards. By virtue of the e. m. f. acting *from*

us in one side, and toward us in the other side of the loop, current is enabled to flow when the ends of the loop are connected together. Were the e. m. f.'s in each side of the loop acting in the same direction they would oppose one another and, as a result, no current would flow.

Now, in order to bring these currents out to the external circuit, we must have some means of connecting the ends of our loop thereto, and, since the loop rotates, the connection must be a movable one. Figure 29 shows each end of the coil connected to a ring mounted on the shaft, the rings being insulated from the shaft and from one another; two metal strips called brushes bear on these Collector Rings, as they are termed, the external circuit being connected to the former. Since the direction of the e. m. f. induced in the coil during one-half its revolution is opposed to that induced by the second half revolution as already explained, it follows that, starting from zero, the current will flow with in-

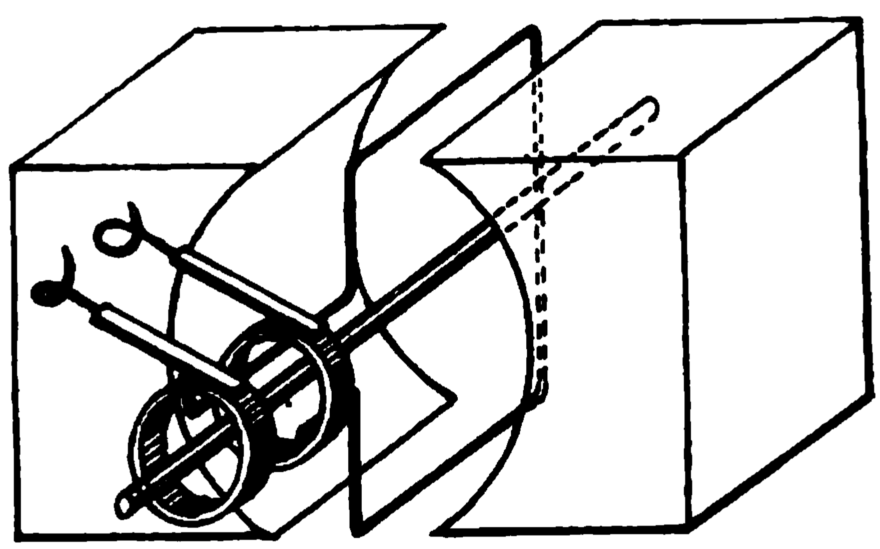


FIG. 29.

creasing strength until the coil has made one-fourth a revolution and then will decrease in value, but still flow in the same direction, until the coil has gone through the second quarter turn or revolution, at which instant it will be zero and will rise to maximum in the opposite direction during the third quarter turn, and decrease again to zero by the time the coil has completed the last quarter turn or the full revolution. Such a current is called an Alternating Current, because its direction is continually reversing or alternating. They have attained a very prominent place in electric light and power work and will, therefore, be treated at greater length farther on. For the present we will consider only Direct Currents, which are those currents whose direction is always constant, that is, flowing in one direction, though of course their strength may vary. In order to obtain direct currents from a dynamo, a different device than collector rings is necessary for conveying the current from the coil to the external circuit; we must have an arrangement which will not only effect this, but

which will also rectify the alternating impulses so that they will all act in the same direction. Therefore, instead of connecting the ends of our coil or loop to the rings as shown in Figure 29, we mount two semi-circular metal strips on the shaft so that each will be insulated from the other and also from the shaft, and connect the two ends of our loop each to one of these segments as shown in Figure 30. Such a device is called a commutator and each section is called a segment, no matter how many there may be. A consideration of the figure will show how the commutator accomplishes its purpose. As the end one of the loop is connected to segment one, and end two is connected to segment two, which segments are revolving exactly the same as the loop it follows that the side of the loop which is rising will always be connected to the upper brush while the down going side will always be connected to the lower brush. And since the direction of the magnetic flux in the field does not change and the direction of rotation also

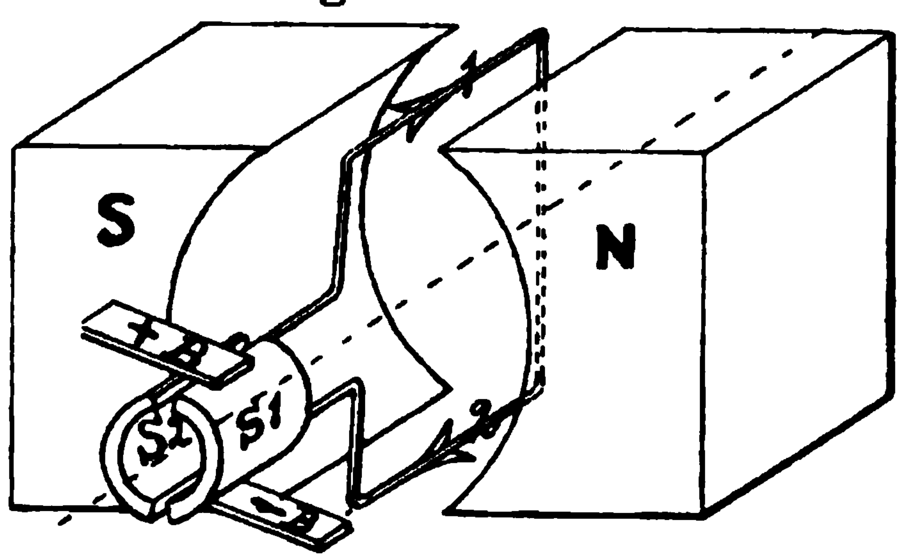


FIGURE 30.

always being the same it follows that the direction of the induced e. m. f.'s must likewise be always the same, that is, if in the right hand side their direction is, say from us, then in the left-hand side their direction would always be opposite to the former, or toward us; hence, as the relative connections between the external circuit and the two ends of the loop undergo precisely the same changes as the loop itself, the current in the former must flow in one continuous direction. For, while in side one of the loop the current is from us, in side two it would be towards us; the current would therefore flow outward from segment two which is connected to the upper brush and out to the external circuit returning to side one of the loop through the lower brush and segment one; as already stated the e. m. f. in this side of the coil is acting from us and is therefore acting in the same direction that the incoming current from the external circuit is, hence the latter will go along that side, and, crossing over at the back, go forward through side two, in which the e. m. f. is acting outward or toward us, thence to segment two and out again to the external circuit. By the

time the coil has gone through one-half a revolution, and the current, therefore, changes its direction in each side of loop, the commutator segments have also changed their positions; segment one now being connected to the upper brush and segment two to the lower brush, as shown in Figure 31. The e. m. f. in side one will now act towards us (instead of from us as before), owing to the fact that it is now cutting the lines of force in an opposite direction to the former one. The side of the external circuit, however, which in the first case was connected to segment two, from which the current flowed out, is now connected to segment one, which latter is now the one from which the current flows. Thus we see that one side of the external circuit is connected alternately with one, and then with the other side of the loop, and, also, that one side of the circuit called the + (positive) side, is always connected, by means of the commutator, to that side of the loop in which the e. m. f. is acting towards us; and the other or

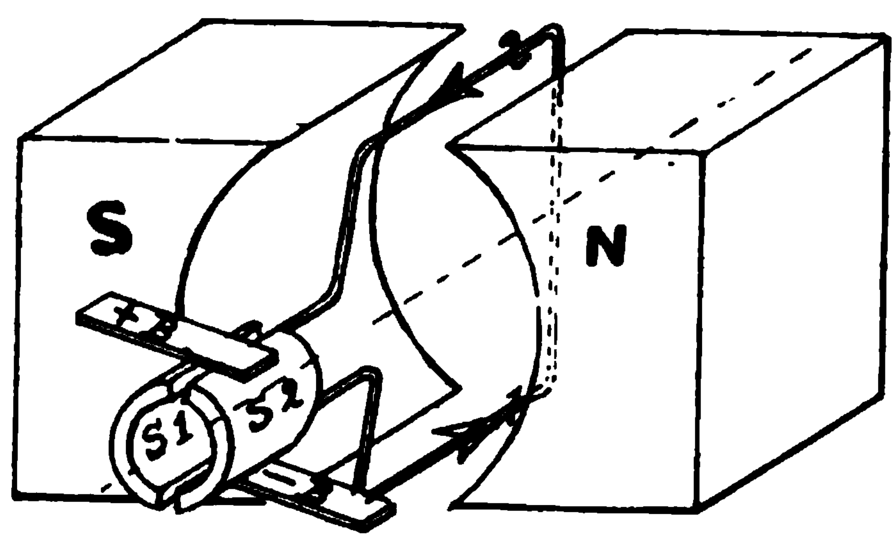


FIGURE 31.

— (negative) side of the circuit is always connected to that side of the loop in which the e. m. f. is acting from us.

In any piece of electric apparatus which causes a flow of current the end from which the current flows out is called the + (positive), and the end which the current flows in is called (negative); while in any receptive device, that is one that is using or consuming current, such as a lamp or motor for instance, the positive terminal is the one at which the current enters, and the negative terminal is the one at which it leaves. A wire that conveys the current out from an electric source is called the + side or leg of the circuit while the conductor which forms the return for the current to its source is the — side.

The strength of the e. m. f. induced in a loop of only one turn would be too small for practical use even if the speed were as high as it could safely be made and the greatest possible density of flux; in order to generate an e. m. f. of one volt the rate of cutting must be 100,000,000 (10^8) per second. The number of magnetic lines in the field multiplied by the number of times they are cut

per second equals the rate of cutting; dividing this product by 100,000,000 gives the voltage generated in one conductor. Let us apply this to our loop. We have a field strength of say 1,000,000 lines, the loop revolves 20 times per second; what is the voltage generated?

Solution: Since there are two sides to our loop we have two active conductors so connected as to assist one another and hence the e. m. f. generated in the two would be double that generated in only one of them; our lines are 1,000,000 but as they are cut twice in each revolution and as the latter $=20$ per second we have a rate of cutting of $2 \times 20 \times 1{,}000{,}000 = 40{,}000{,}000$; multiplying this by the number of conductors we have: $40{,}000{,}000 \times 2 = 80{,}000{,}000$ and since $\dfrac{\text{rate of cutting} \times \text{number of conductors}}{100{,}000{,}000}$ equals the voltage we have:

$$\frac{80{,}000{,}000 \times 2}{100{,}000{,}000} = \frac{160{,}000{,}000}{100{,}000{,}000} = 1.6 \text{ volts.}$$

We can increase the voltage readily by increasing the rate of cutting which can be done either by increasing the field strength, that is the number of lines or the flux density, by increasing the speed, or by increasing the number of conductors, or a combination of any two, or even a simultaneous increase of all three factors.

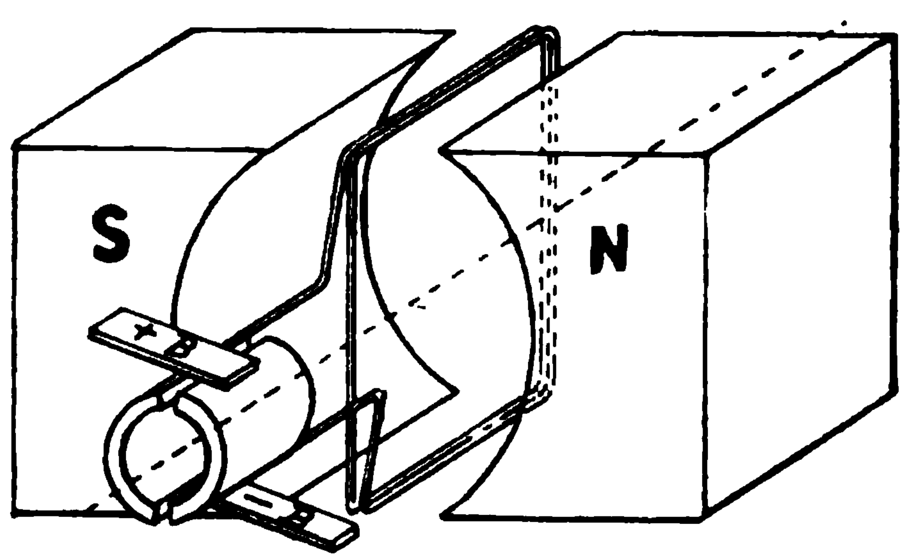


FIG. 32.

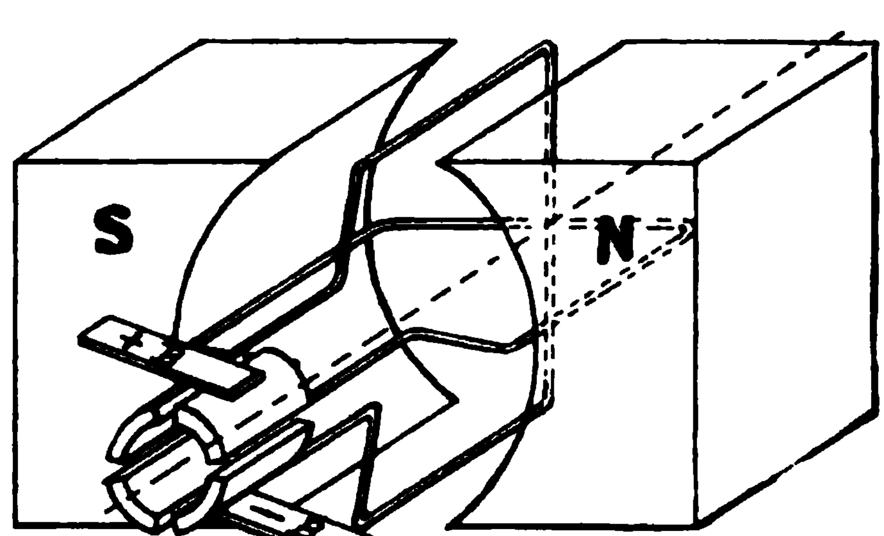


FIG. 33.

A little thought will show that we can increase the rate of cutting in either one of the three ways mentioned, since, if we have a coil consisting of one turn or loop of wire revolving 10 times a second in a field the strength of which is 100 lines, our rate of cutting will be $10 \times 100 = 1000$. If we now increase our lines of force to 1000, the rate of cutting, leaving the speed of rotation the same, would be $1000 \times 10 = 10{,}000$. Likewise if we increase the speed of rotation to 100 revolutions per second and leave our field strength at 100 lines we would thereby also obtain a rate of cutting of 10,000. Or, leaving both the speed of rotation and strength of field the same as in the first case, namely, the former at 10 and the latter at 100, but increase the number of turns in our coil to 100 we would obtain a rate of cutting equal to $10 \times 100 \times 100$, which equals 100,000. We can, however, increase each of the three factors without difficulty. Let us take two coils, for instance, as in Figure 32, in which case, with the same speed and field strength as in the previous case the e. m. f. would be double. Figure 33 shows a 4-loop arrangement, which would quadruple the e. m. f., the other factors remaining the same. It will be noticed that there are as many segments in the commutator as there are turns or coils and the end of one turn is connected to the same segment that the beginning of the next turn is connected to, thus forming a closed circuit of the several loops with leading out connections coming down to the commutator.

CHAPTER V.

THE DYNAMO IN DETAIL.

The principal parts of a dynamo are the field magnet, the armature, the commutator or collector rings, brush holders and brushes, and the bearings.

The field magnet is the heaviest part of the machine, and is usually made of cast iron or steel, while the poles and pole-pieces, which are considered part of the field magnet, are generally made of wrought iron cast-welded into the magnet frame or bolted thereto.

Figures 34-38 show cross-sectional views of different types of field magnets. The field coils which energize the magnet are usually wound on spools or bobbins which are slipped over the poles, being held in place by the pole-piece, which latter also serves to give the magnetic flux better distribution over the surface of the armature. In the figures, A is the magnet frame, B the poles, and C the pole-pieces. D, Figure 37, is a magnet coil, or field coil, as they are generally called, removed from the frame. Figure 34 is a bi-polar field, that is, having but two poles;

the field coils are so wound and connected that N-polarity is produced at one pole and S-polarity at the other. Figure 35 shows a 4-pole field, with but two field coils; the poles at bottom and top are called consequent poles. The field coils are so connected that the same polarity is produced at opposite poles; therefore, there will be but four magnetic circuits, as shown by the

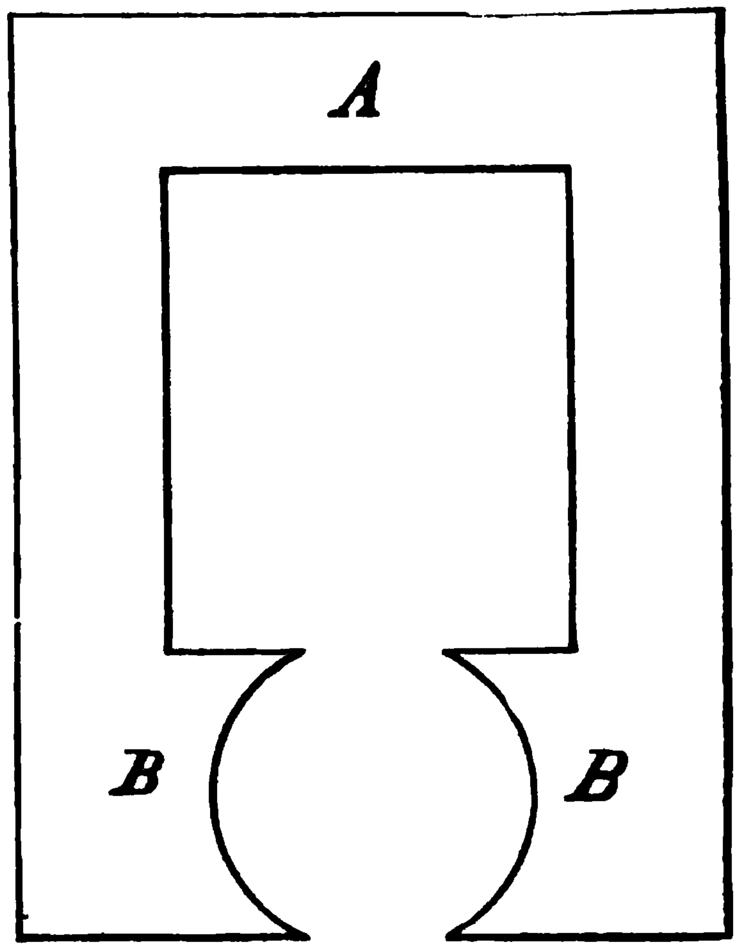


FIG. 34.

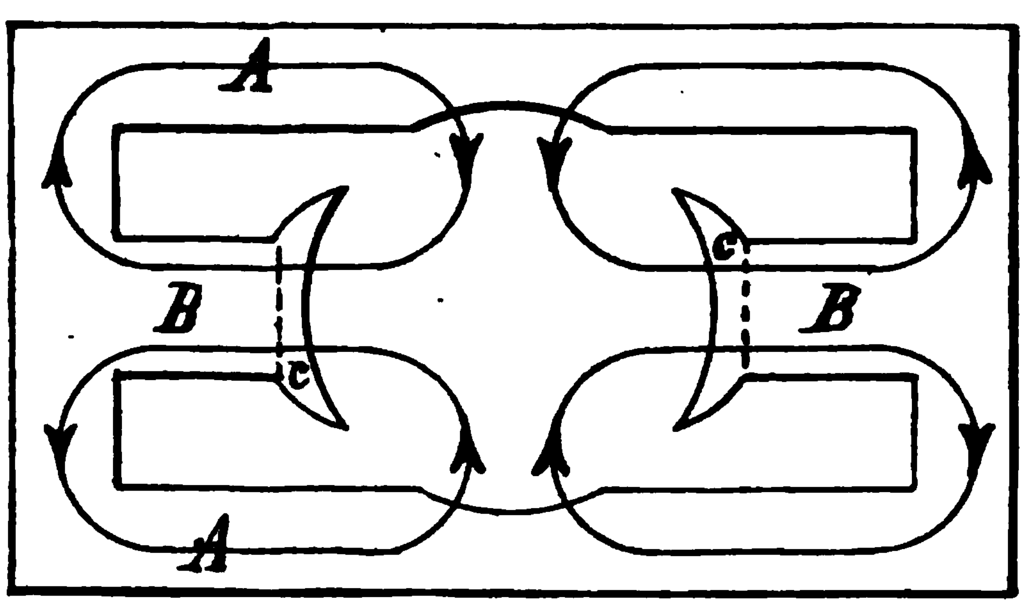


FIG. 35.

figure. This type is not used for generators, but is frequently used for motors in the medium and smaller sizes. Figure 36 shows a 4-pole field; the field coils are connected so as to produce like polarity at opposite poles and unlike polarity at any two neighboring poles. There are four magnetic circuits as shown. Figure 37 shows one with six poles, the field coil connections being precisely the same as those in Figure 36, viz.: to produce opposite polarity at neighboring poles.

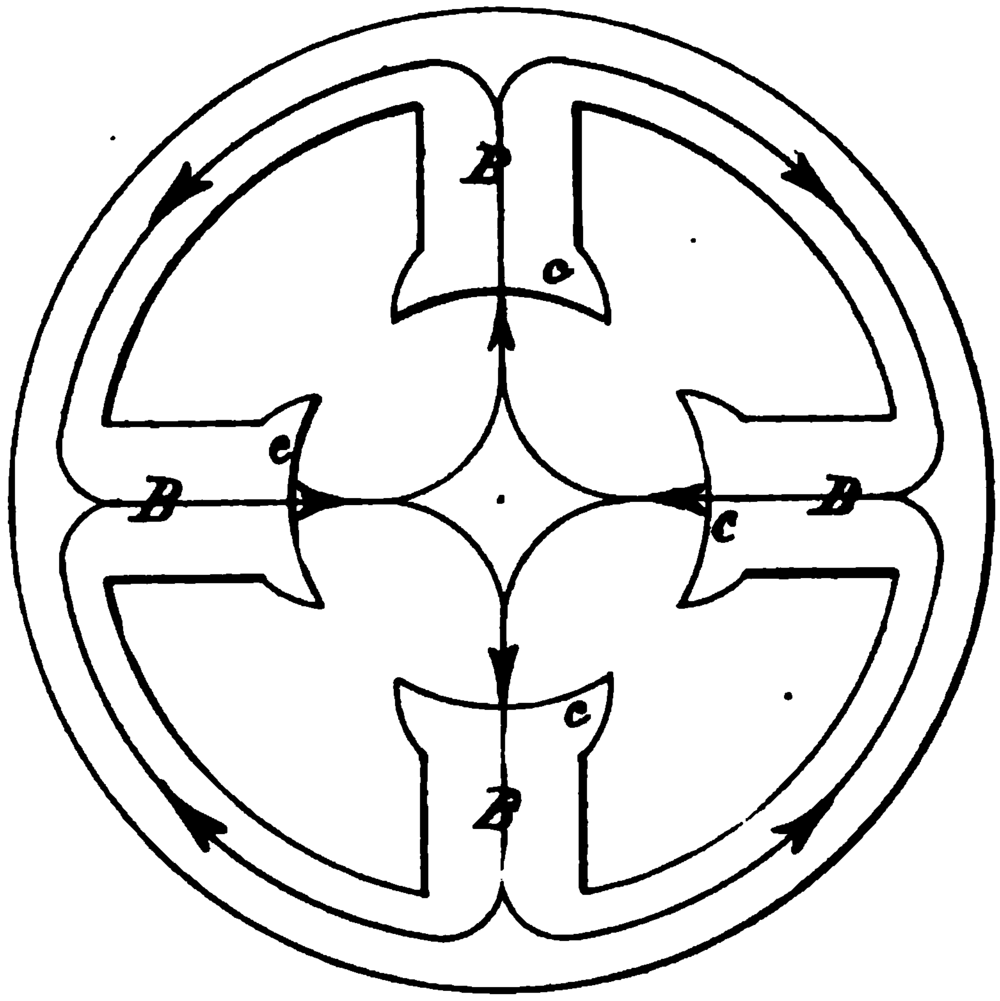


FIG. 36.

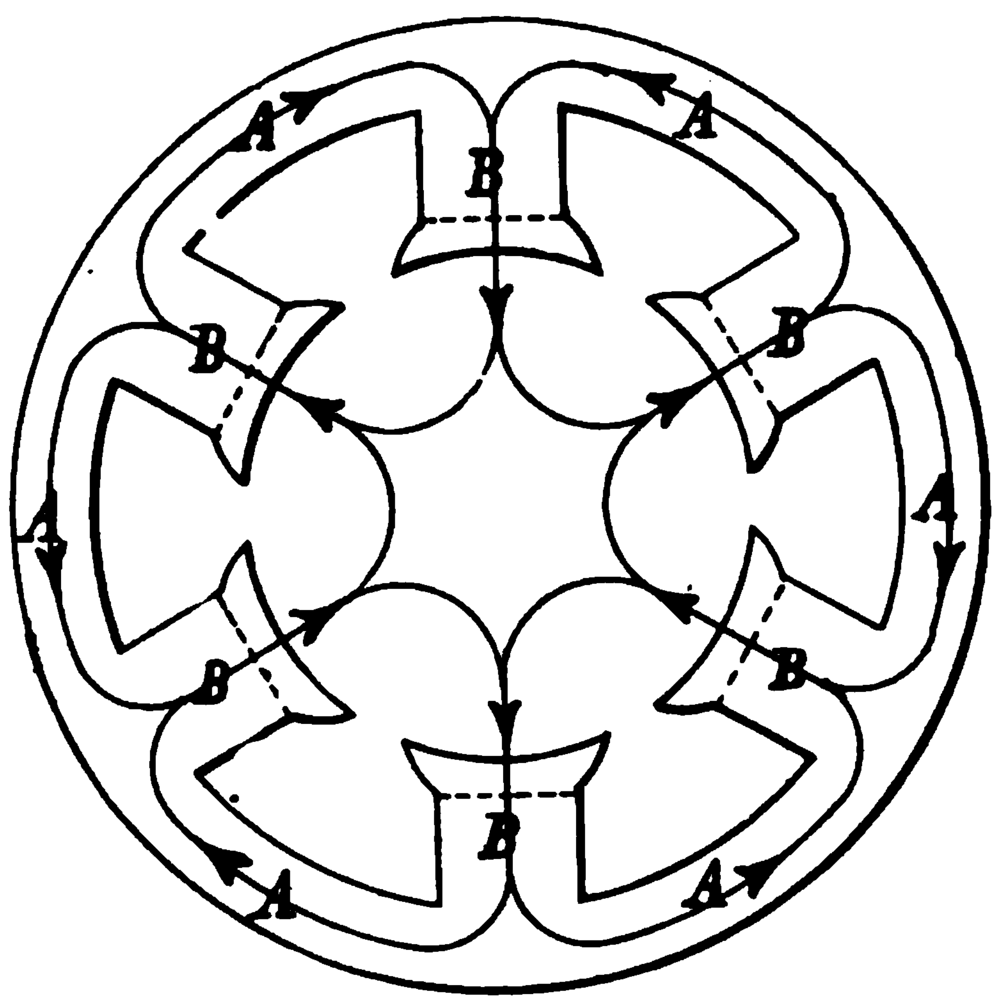


FIG. 37.

Figure 38 shows the field frame of an alternator, these having a greater number of poles than d. c. (direct current) machines. Dynamos having but two poles are called bi-polar, and those having four or more poles are called multi-polar machines. It will be noticed that in each of the figures the pole pieces have

their inner side shaped so as to produce a circular space for the reception of the armature which rotates therein.

The armature is the vital part of the machine; it consists of an iron core mounted on a shaft which is supported by bearings so that it can revolve freely. On the face and ends of this core the coils, wherein the e. m. f.'s are generated, are wound, as shown in Figure 39. The function of the iron core is chiefly

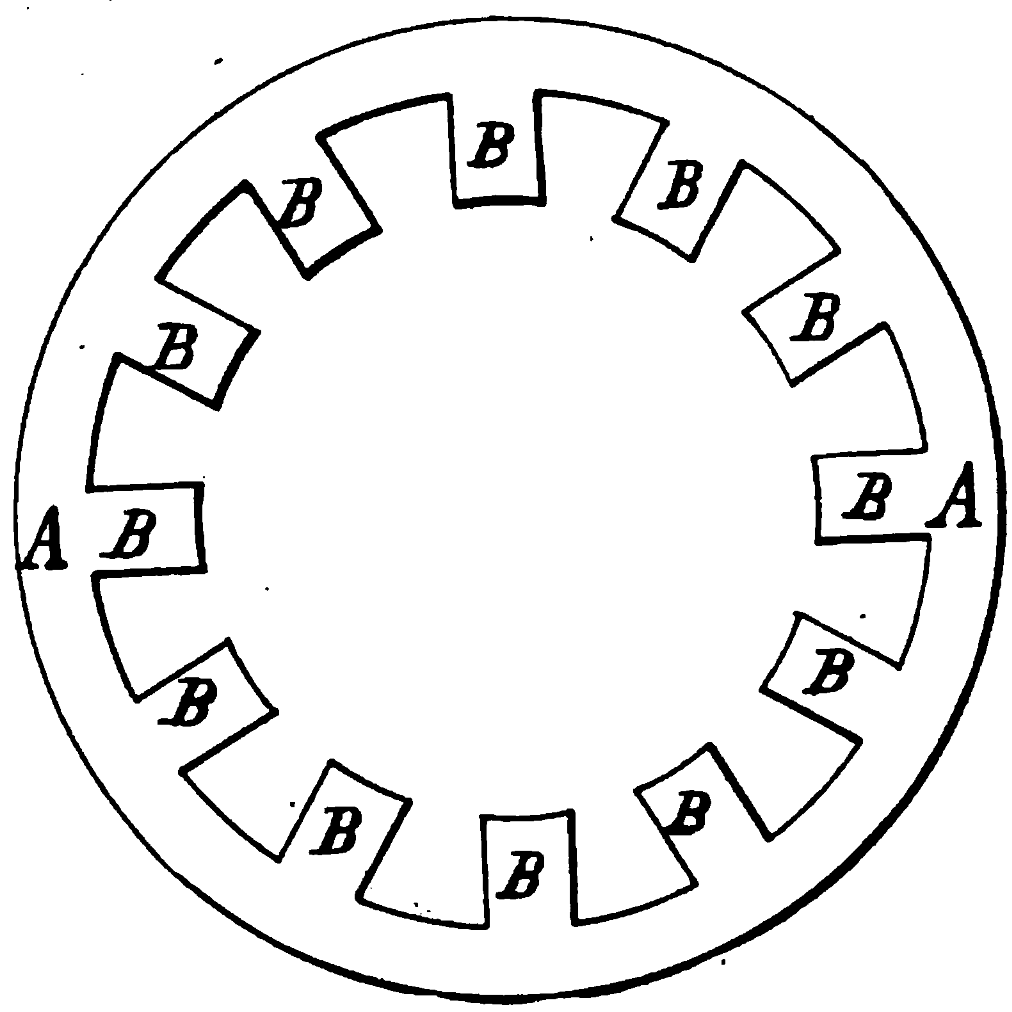


FIG. 38.

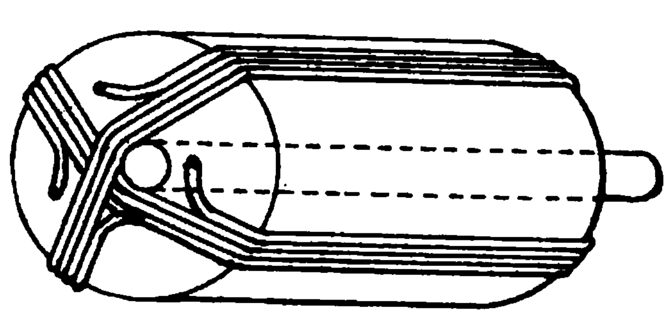


FIG. 39.

to reduce the reluctance of the air gap between the poles of the field magnet. Were there no iron placed therein the reluctance of the wide air-gap would enormously reduce the magnetic flux, and hence, also, the e. m. f. generated. Since the flux equals the e. m. f., divided by the reluctance, it follows that the greater the latter the less will be the flux; and the less the flux the lower the e. m. f. set up with any given speed of rotation. Upon the shaft, also, the commutator is mounted, but it may be taken off separate from the armature core. The core is not a solid piece of iron, but is built up of sheets of sheet-iron, which are insulated from one another by a film of some insulating substance, for the

purpose of preventing the generation of eddy currents in the iron, which would cause it to become very hot. Figure 40 shows the paths taken by these eddy currents in a solid armature core, the core being shown split. The e. m. f. of these currents would of course be very low, but as the resistance of such a short length of iron of such large cross-section is also small it is evident that the currents would have considerable magnitude. Building up the core of thin sheets of iron which are insulated from one another prevents these eddy currents, since the direction of the latter is parallel to the shaft. Owing to the fact that the e. m. f.'s induced in the core are very low a thin film of insulation is sufficient to prevent a flow of current.

The sheets in moderate sized machines are fastened to the shaft by means of a spider, which latter is keyed to the shaft. In small machines the discs are merely slipped onto the shaft, a hole being made in the center for this purpose, and are held in

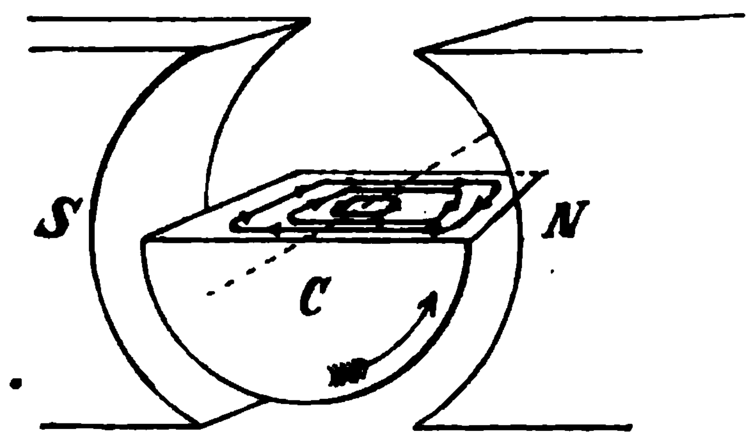


FIG. 40.

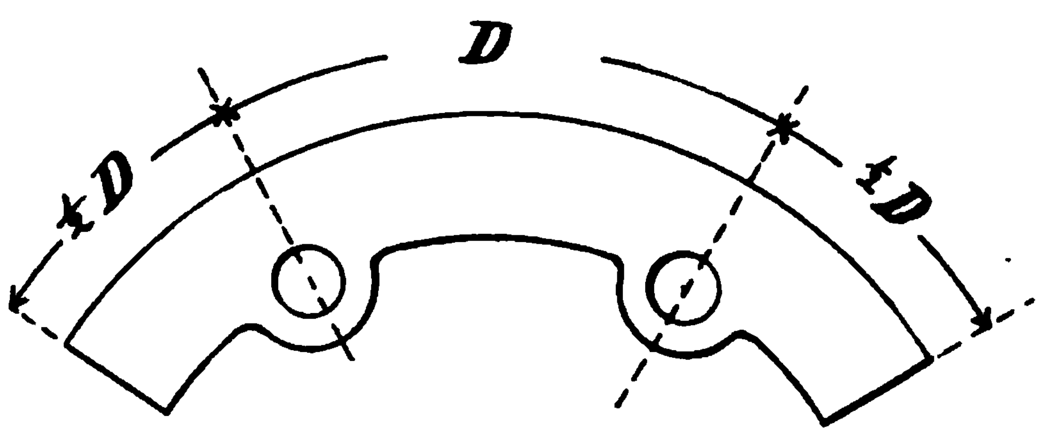


FIG. 41.

place at one end by a shoulder on the shaft and at the other end by means of a nut, the pressure of the latter serving to bind them firmly to the shaft. In such a case the two end discs are made considerably heavier than the others to prevent the discs flaring out at the outer edges when the nut is screwed tight. In large armatures the discs are not made in one piece, but are cut in sections as shown by Figure 41, the joints between the segments of one layer coming in the center of the neighboring layer. The whole is bound together by bolts passing through holes in the segments, which bolts may also serve to secure them to the spider.

In large machines and even in some moderate sized machines, openings, called air-ducts, are provided for the passage of air from the inside of the core to the outside, this flow of air serving to keep the armature cool. This is accomplished by the arrangement of the segments, one of the latter being omitted occasionally. Each manufacturer has his own method of ventilating the cores of his armatures, therefore it would be a waste of space to go into details on this subject. The core, after being secured together and insulated, is then ready for the winding, which is disposed on the face and ends thereof. There are two types of armatures, viz: the drum and the ring type. The core of the latter type is built so that there is a considerable clear space between the shaft and the inner edge of the core. In winding such an armature the wire goes along the outside, say from front to back, and goes from back to front on the inside of the core, as shown by Figure 42. Sufficient wire for one or

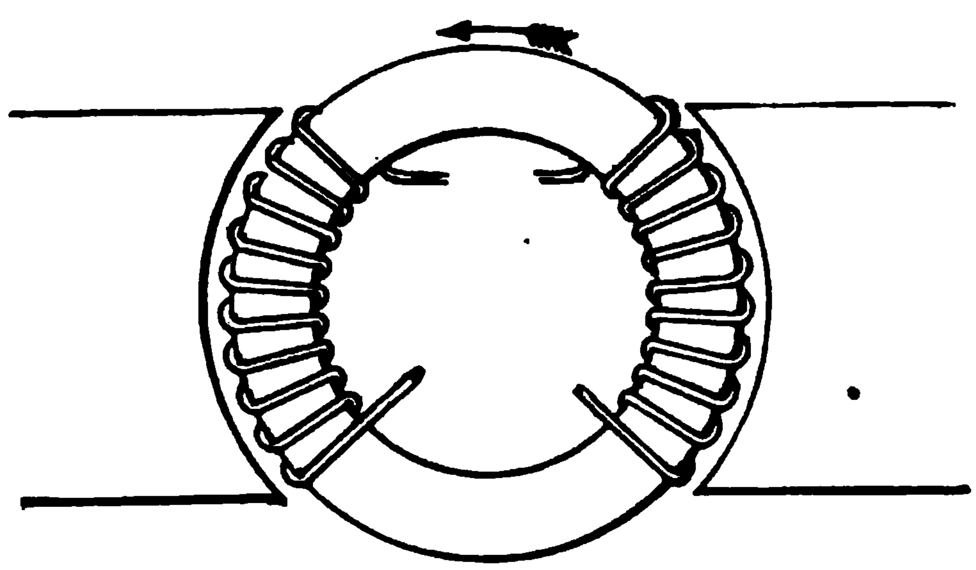


FIG. 42.

two coils is wound on a shuttle made somewhat long and narrow to facilitate passing same through the inside of the core between the arms of the spider. The main advantage of the ring armature over the drum type lies in the absence of a lapping over one another of the coils, which is unavoidable with the latter type, and the ease of repairing or replacing damaged or burned out coils, as any one can be taken off without disturbing the rest. Moreover, the chances of making a mistake in the connections of a ring winding to the commutator are less than with the drum type. The disadvantage is the greater length of wire needed for a given out-put; there being no lines of force cut by the wires inside the ring, there can be no e. m. f. induced in that portion of the winding, hence all inner conductors are inactive as far as induction is concerned. They act only as conductors and therefore increase the resistance of the winding without increasing the output. For certain classes of work, however, the ring winding is preferable, nevertheless. Nearly all arc light machines have

ring wound armatures; the high voltage generated by these machines would make it a difficult matter to insulate the different coils one from another in the drum winding owing to the overlapping or crossing of coils between which there is a great difference of potential. In a ring winding those coils are farthest apart between which the highest voltage exists, hence the danger of a short-circuit is almost entirely obviated. The connections of the coils to the commutator are shown by Figure 42a; the be-

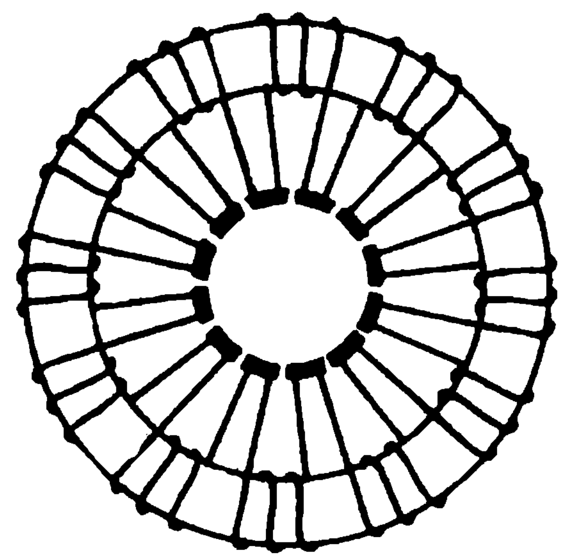


FIG. 42a.

ginning of coil number one is connected to segment number one, and the end of coil one is connected to segment two; the beginning of coil two to segment two and the end of coil two to segment three, and so on all around. The end of the last coil being connected to segment number one, to which the beginning of coil one is connected, makes the winding a continuous one, just as if the entire winding were one wire (see Figure 43) with taps at regular intervals coming out to the commutator.

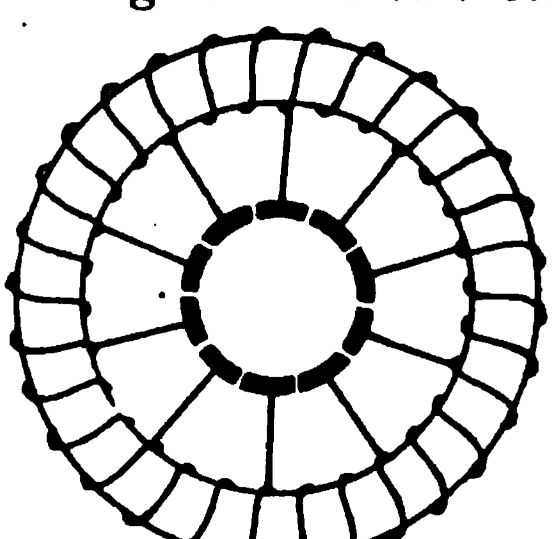


FIG. 43.

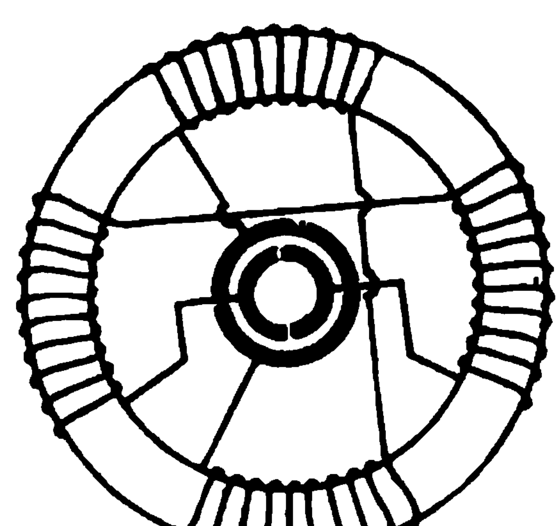


FIG. 44.

Such a winding is called a closed-coil winding, because the entire winding is connected into one continuous coil and tapped out at regular intervals for connection to commutator segments. Open coil windings are such where the ends of a coil are connected to diametrically opposite commutator segments, as shown by Figure 44, which shows an open coil ring winding of 4 coils,

two in series, each two coils being connected to a two-segment commutator. For convenience the two commutators are shown one within the other. It must be understood that where the wires cross they are supposed to be insulated from one another. The Brush, the Thomson-Houston and the Westinghouse arc machines have open coil armatures.

In the drum winding all of the wire is on the outside of the core whether the latter be solid or hollow. Instead of the conductor returning to the front end through the core as in the ring wound type, it is carried clear across the back end of the core to a point nearly diametrically opposite and then brought across the face to the front end; across the front, and around the same path again until the coil has the desired number of turns. The ends are connected to the commutator segments as shown in Figure 45, which shows a drum armature with one

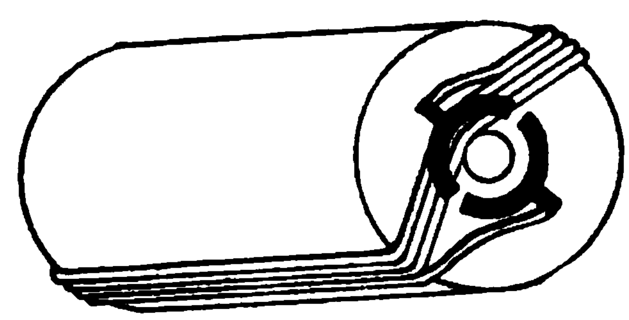


FIG. 45.

coil of 4 turns. As the current from such an armature would fluctuate or pulsate very badly, being zero when the coil is at right angles with a line through the centers of the pole pieces and maximum when it is lying parallel thereto more coils should be put on so that there shall always be some active coils. We will put on more coils and divide our 2-segment commutator into as many segments as we have coils and connect each of the latter across one of the gaps as shown by Figure 46, which shows four coils instead of only one. Special precaution is taken to prevent

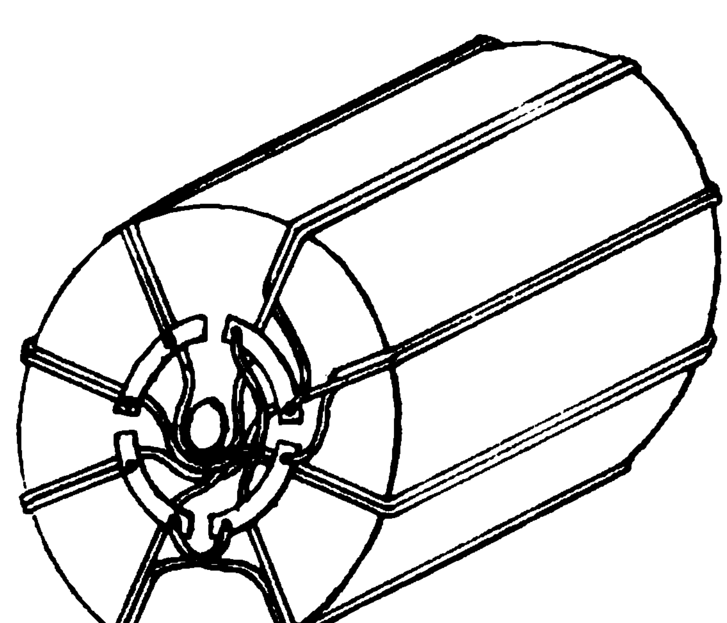


FIG. 46.

electrical contact between the overlapping coils by the insertion of oiled muslin or some other insulating substance. Our 4-coil armature would still have an insufficient number of coils for satisfactory illumination. Therefore, in practice, the number of coils is made considerable greater and the number of commutator segments is correspondingly increased. Having completed the winding, some means must be provided for holding the wires in place on the core in both the ring and drum type, since, as the armature rotates, centrifugal force would cause them to fly out. For this purpose binding wires are wound around the armature; they are generally of german silver. Strips of mica are put on the armature first, and over these the binding wires are wound. The object of the mica strips is to insulate the armature coils from the binding wires, as contact between the latter and a coil would ground the winding on the core, and if two grounds would occur at once the portion of the winding between the two grounds would be short-circuited and would heat excessively and, very likely, burn out; that is, the insulation on the coils would become charred by the heat and the different coils or different parts of one coil would come into electrical contact and the machine would be ready for repairs.

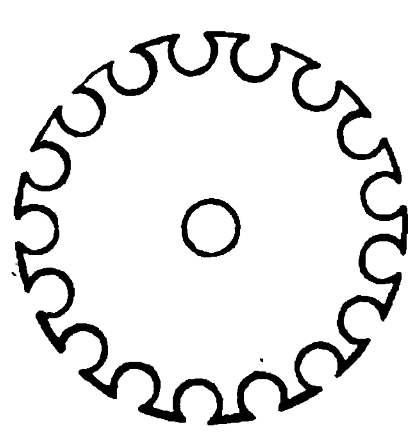


FIG. 47.

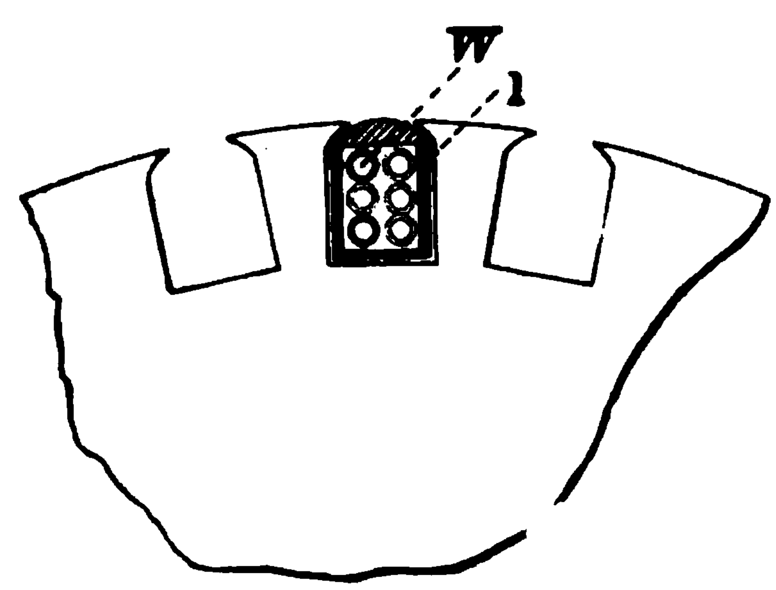


FIG. 48.

Armatures so far considered are known as smooth core armatures. However, most armatures in use at the present day have toothed or slotted cores, the winding being laid or wound in the slots. Figure 47 shows a cross-sectional view of a toothed core, or, as they are also called, an iron-clad armature. The slots are narrowed somewhat at the outside, as a rule, though some armatures have slots with straight sides. The latter necessitate the use of binding wires to hold the winding in the slots. In the other kind strips of hard wood, cut to fit the slots snugly, are driven into the slots after the winding has been put on. See Figure 48, which shows a cross-sectional view; I is a trough of insulating material and W a hard-wood wedge.

The advantage of the iron-clad over the smooth core lies in the absence of binding wires, the protection of the winding from mechanical injury and the firmness with which it is held in place resulting in an absence of vibration of the wires, which vibration would in time destroy the insulation. The clearance, that is, the space between the armature and the pole-pieces, can also be made considerably less in machines with iron-clad than in those with smooth core armatures.

While the armature is the vital part of the dynamo the commutator is the vital part of the armature. Most dynamo troubles originate there, and frequently the commutator gets the least attention and care.

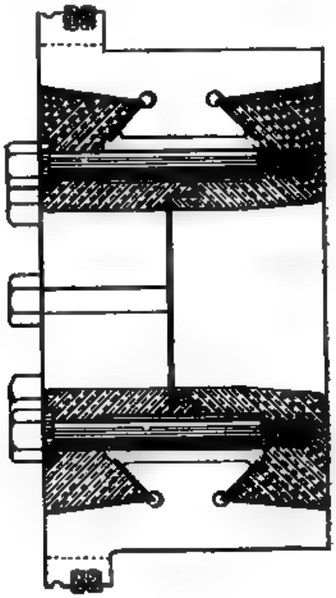


FIG. 49.

The commutator consists of an iron shell made in two parts, in such a manner that it will securely hold the bars or segments when the two parts are bound together by the screws or bolts which are provided therefor. Figure 49 shows a cross-sectional view of a commutator. The bars or segments are made of copper and are shown light in the figure; the heavy black lines represent mica insulation between the individual bars and between them and the shell. At one end the bars have a projection or lug into the tops of which a groove is cut for the reception of the armature leads which are soldered into them, or sometimes

fastened thereto with binding screws. In order that the insulation may be of equal thickness between the entire depth of the bars the latter are made thicker on the outside than on their inner edge.

The brushes are supported by a rocker-arm usually fastened to the bearing in such a manner that the position of the brushes may be shifted in either direction around the commutator. They are made of copper, phosphor-bronze or carbon. The latter are preferable, because they cut the commutator less than copper brushes and also because the effect of sparking is almost entirely confined to the brushes, thereby greatly increasing the life of the commutator. Owing to the high resistance of carbon, however, they are seldom used on machines whose voltage is less than 110. They are generally copper plated, in order to reduce their resistance. Copper and phosphor-bronze brushes are made of woven wire or of sheets or strips of the required width, used either singly or a number of sheets or leaves being taken together to give the brush the proper thickness. The leaves are soldered together at one end, but the soldered end is never put on the commutator.

The bearings are generally of the self-oiling type, which are so well known at this day that a description of them is superfluous. A belt-tightening device is also furnished with all machines on which a belt is used. The machine is mounted on slide rails, which are firmly secured to the insulating frame, to the floor or the foundation. By means of a screw, or screws, provided therefor, the machine can be moved along the slide rails until the belt has the proper tension. Insulating frames, made of wood saturated with oil or other moisture preventive, are furnished with all except large machines, to insulate the frame of the machine from the ground. Large machines are generally mounted directly on the foundation, owing to their great weight.

Dynamos are divided into two general classes, viz: direct current and alternating current machines; the latter are usually called alternators.

D. c. machines are divided into constant-current and constant-potential machines. In the former the current strength is constant and in the latter the e. m. f. is constant, or practically so, at all loads. The former are used exclusively for series arc lighting and the latter for supplying current for motors, arc and incandescent lamps and other apparatus. Constant-current machines have series-wound fields; the fields, the armature and the lamps in the circuit, are all connected in series, hence the current strength is the same in all portions of the entire circuit.

Constant-potential machines are either shunt-wound or compound-wound. In shunt-wound machines the field coils are connected in shunt to the armature, that is, directly across the

brushes; therefore, as they are subjected to the full armature voltage, their resistance must be such that no more current than the coils can carry without over-heating will flow through them.

As the load on such a machine is increased, the e. m. f. falls slightly, owing to the armature reaction upon the field, the latter being weakened thereby. This armature reaction becomes greater as the load increases. As the lamps or motors supplied by the machine are connected in parallel we can readily understand that the current will be greater the more lamps or motors are cut in, as each additional one provides an additional path for the flow of current. As a variation in voltage is undesirable some means of regulation must be provided to maintain it constant. For this purpose a resistance, called a field rheostat is connected in series with the field coils. This resistance can be varied at will. At light loads the resistance is all in circuit, and as the load increases parts of it are cut out, which permits more current to flow through the field coils, thus strengthening the field and thereby increasing the e. m. f. As this requires hand manipulation, however, it will be readily understood that with a frequently varying load constant attention would be required to maintain uniform voltage, and if the fluctuations of the load were rapid a uniform voltage would be impossible, even with continuous manipulation of the rheostat. Therefore, shunt machines are used only where the load is constant or at least the variations in load are not frequent, as for instance a load consisting entirely of incandescent lamps. For motor loads, machines whose regulation is automatic are employed. Almost perfect regulation can be obtained in compound-wound machines. The compounding is effected by the addition of a few turns of heavy wire to the shunt winding. The two windings are insulated from one another, and the heavy one is connected in series with the armature, hence must be of sufficient size to carry the entire armature current. This winding being in series with the armature and the external circuit, it follows that the current strength will vary in the former precisely as in the latter; hence, at heavy loads the effect of the increased current through the series winding will be to strengthen the field, thus counteracting the effect of the armature reaction mentioned above. As it is impossible to determine the exact number of turns of wire required in the series coils for close regulation, more are put on than are really needed. The proper compounding effect is then obtained by shunting this series winding by a german silver resistance, and, by changing the length of the latter, the proper degree of compounding is obtained. This compound winding is sometimes adjusted so that the machine voltage will be higher at full load than at no load, in which case the machine is said to be over-compounded. The amount of over-compounding is

generally expressed as a given per cent of the voltage of the machine at no load; thus, a machine whose voltage is 500 at no load and 550 at full load is said to be 10 per cent over-compounded, meaning that the over-compounding is such as to cause the voltage of the machine at full load to be 110 per cent of the no-load voltage. At various loads between no load and full load the voltage will be in proportion to the load. The object of this over-compounding is to compensate for the drop of voltage in the lines. This drop increasing as the load increases, it follows that the more current that flows the lower would be the voltage at any point in the line. Therefore, to maintain the voltage in the line constant, or nearly so, at all loads, the machine is over-compounded.

Dynamos used for supplying current for d. c. series arc lamps are known as constant-current dynamos, since the current strength is always practically constant, regardless of the number of lamps in circuit. Since all the lamps are connected in series it follows that to take care of an increase of load we must increase the e. m. f. in order to force the required current through the increased resistance of the additional lamps, and as the number of lamps is decreased the voltage must also be decreased, as otherwise the current would become too great owing to the decreased resistance of the circuit. Therefore, the function of a regulator for this class of machines is to change the e. m. f. of the machine to suit the load. Figure 50 shows a T-H arc armature drum wound

FIG. 50.

and Figure 50a shows the ring armature, both of which are of the open coil type. This armature is spherical in shape, and the winding of the drum type consists of three coils, one end of each of the three being connected to a metal ring at the back of the armature; in the ring type there are three groups of ten coils each, as shown. The other ends are connected to a three-segment commutator. Four brushes are used, they being connected in pairs, as shown. With the direction of rotation as indicated by the arrow, the line n, n is the line of least action, and as soon as a coil gets into the position of least action it is momentarily disconnected, being connected immediately after in parallel with

FIG. 50a.

the coil behind it, the two in parallel being in series with the remaining coil. The changes that take place in a half revolution therefore, are: One coil is first in parallel with the coil behind it, then momentarily disconnected, then it is connected in parallel with the coil ahead of it, then connected in series with the other two, which latter are then connected in parallel. Further movement of the armature repeats this series of connections. Regulation is obtained by means of the brushes, which are so arranged as to permit the span, or the arc of contact, as it is called, between the brushes to be varied by an arm actuated by the regulating magnet, which performs the operation automatically, as follows: The primary and secondary brushes are mounted on separate rocker-arms, which are connected together by suitable arranged

levers in such a way that when the primary brushes are shifted forward the secondary brushes are shifted backward, or vice versa. A magnet mounted on the frame of the machine has fastened to its armature a lever, which latter moves the primary brushes back and the secondary brushes forward when the magnet armature is pulled up. This reduces the e. m. f. of the machine. This magnet is energized by the current in the main line; it is not continually in circuit, however, but is cut in and out, as required, by a wall controller located at any convenient place. Figure 51 shows the connections of the apparatus. R is the regu-

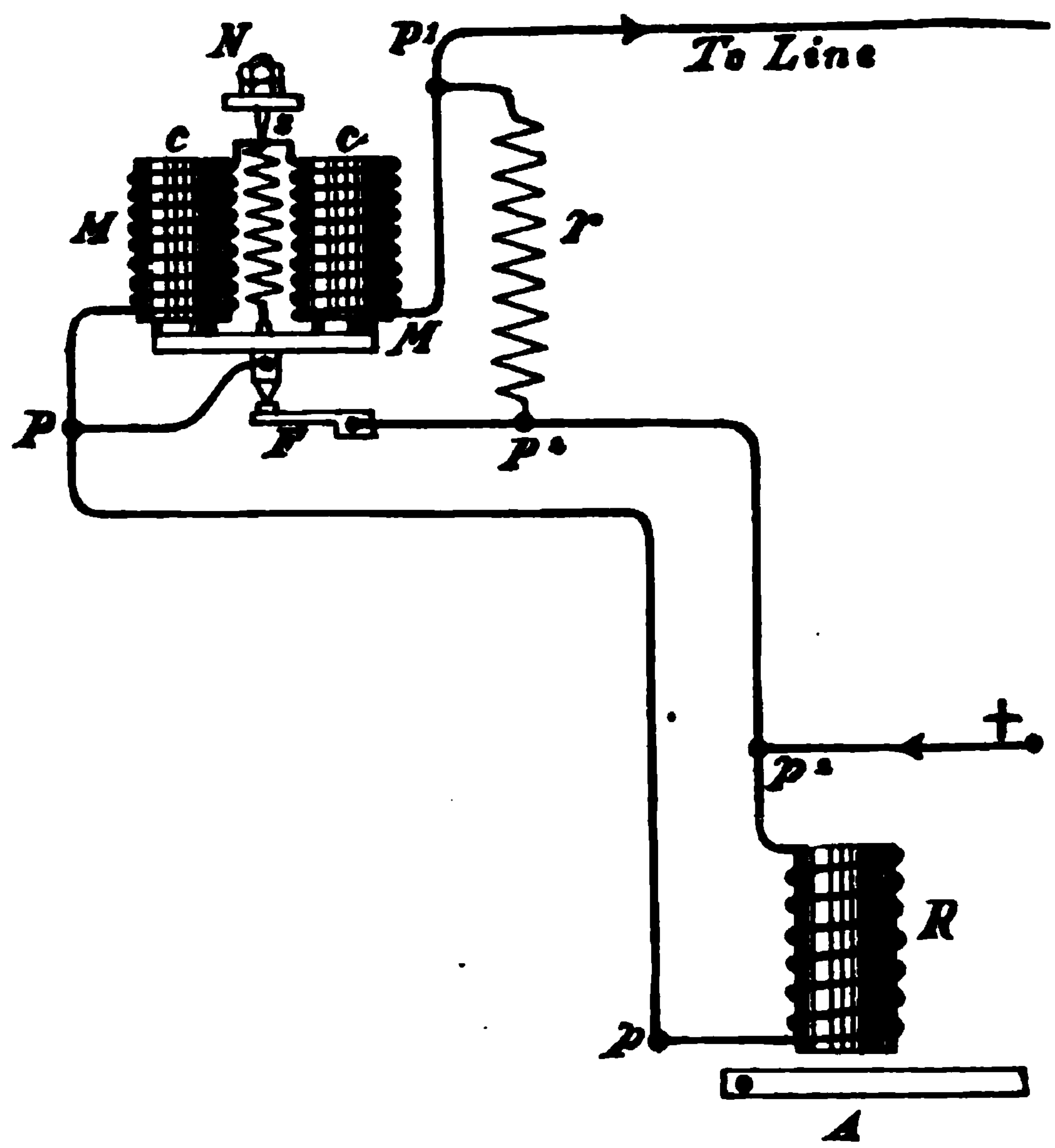


FIG. 51.

lating magnet and A its armature to which is secured the lever which moves the rocker-arms, M M are the coils of the controlling magnets, C C being movable cores. The spring S partially balances their weight; the pull of this spring can be adjusted by the thumb nut at the top. The cores carry a contact point which rests on a fixed contact F, when the cores are down. The line current goes through the controlling magnet and thence to the line. While the line current is at normal strength the magnet can not raise the cores and the contact F, hence the regulating magnet remains short-circuited and no current can flow through it. As soon as the current in the line exceeds the amount that the apparatus is adjusted for the cores are raised and the contact at

F is broken, cutting the regulating magnet into circuit, which latter then pulls up its armature and shifts the brushes, reducing the e. m. f. of the machines and hence the current. The contact F is shunted by a high resistance, which prevents the current arcing across the gap between the contacts when the connection is broken at F, which it would otherwise do, owing to the self-induction of R.

In order to get rid of the spark that occurs when a segment passes from under the secondary brushes a puff of air is blown at the end of the secondary brushes which blows out the spark as soon as it occurs, preventing it from doing any damage. The air blast is furnished by a small rotary blower mounted on the shaft of the armature between the bearing and the commutator. Figure 52 shows correct position for the air jets. It is necessary that

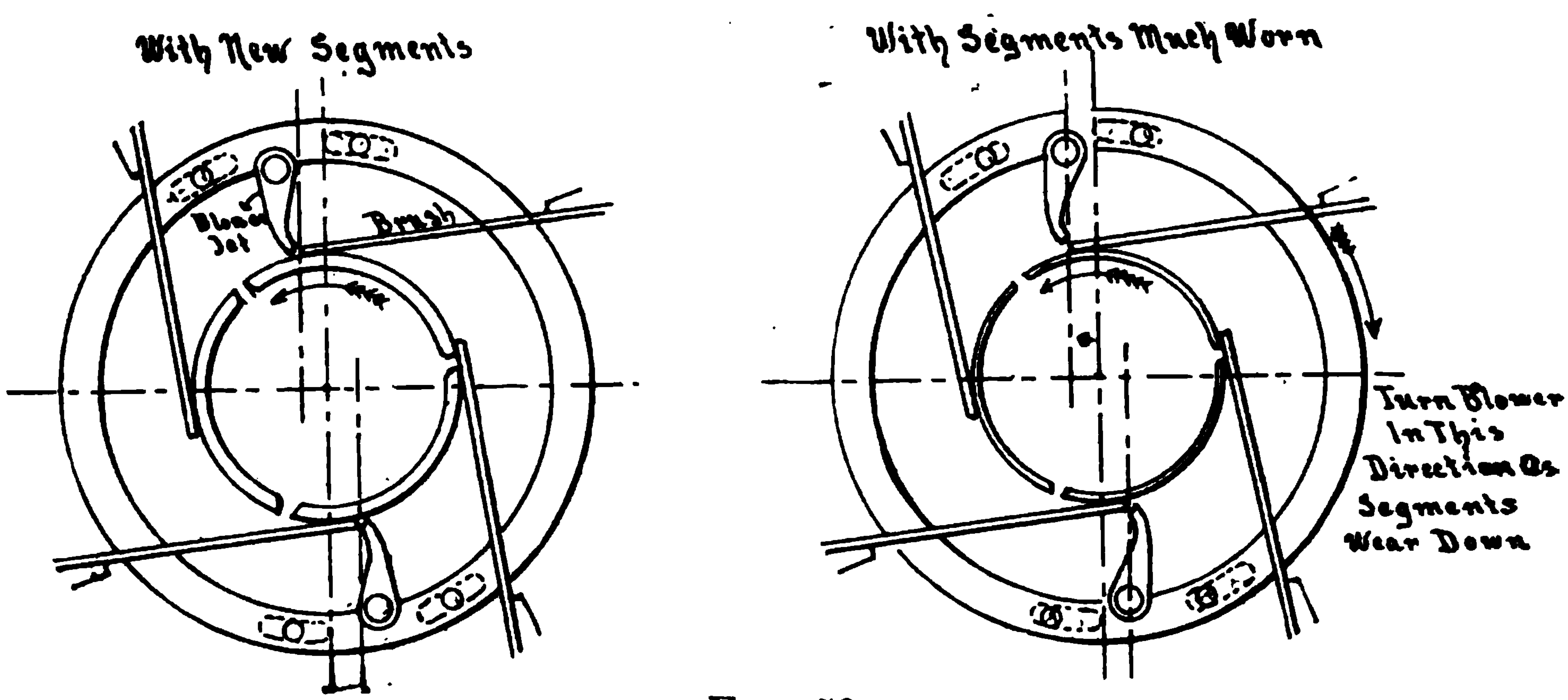


FIG. 52.

these be carefully adjusted, so that the puff occurs at the same time the spark does. The tip of the jet should be in line with the tip of the brush and should clear the commutator 1-32nd of an inch. The air blast should be turned against the direction of rotation of the armature as the segments wear down, to follow the changed position of the brushes.

Figure 53 is a diagram of a Brush arc armature, which also belongs to the open coil type. It is ring wound, as shown. Instead of being outside the periphery of the armature, the pole-pieces face the armature at its sides, being represented by dotted lines. Such an armature has two commutators, each of four segments, mounted side by side on the shaft. For convenience of illustrating they are shown concentric, however. The winding is in two parts, each part consists of four coils 90 degrees from

each other, opposite coils being connected in series and connected to one of the commutators as shown. The other part of the winding is a duplicate of the first, the coils also being 90 degrees from one another, and are placed between those of the other winding. Opposite coils are connected in series and to the second commutator as shown. The two windings are connected in series, the positive brush of one winding being connected to the negative brush of the other and the line wires are connected to the two remaining brushes. As the e. m. f. in one of the wind-

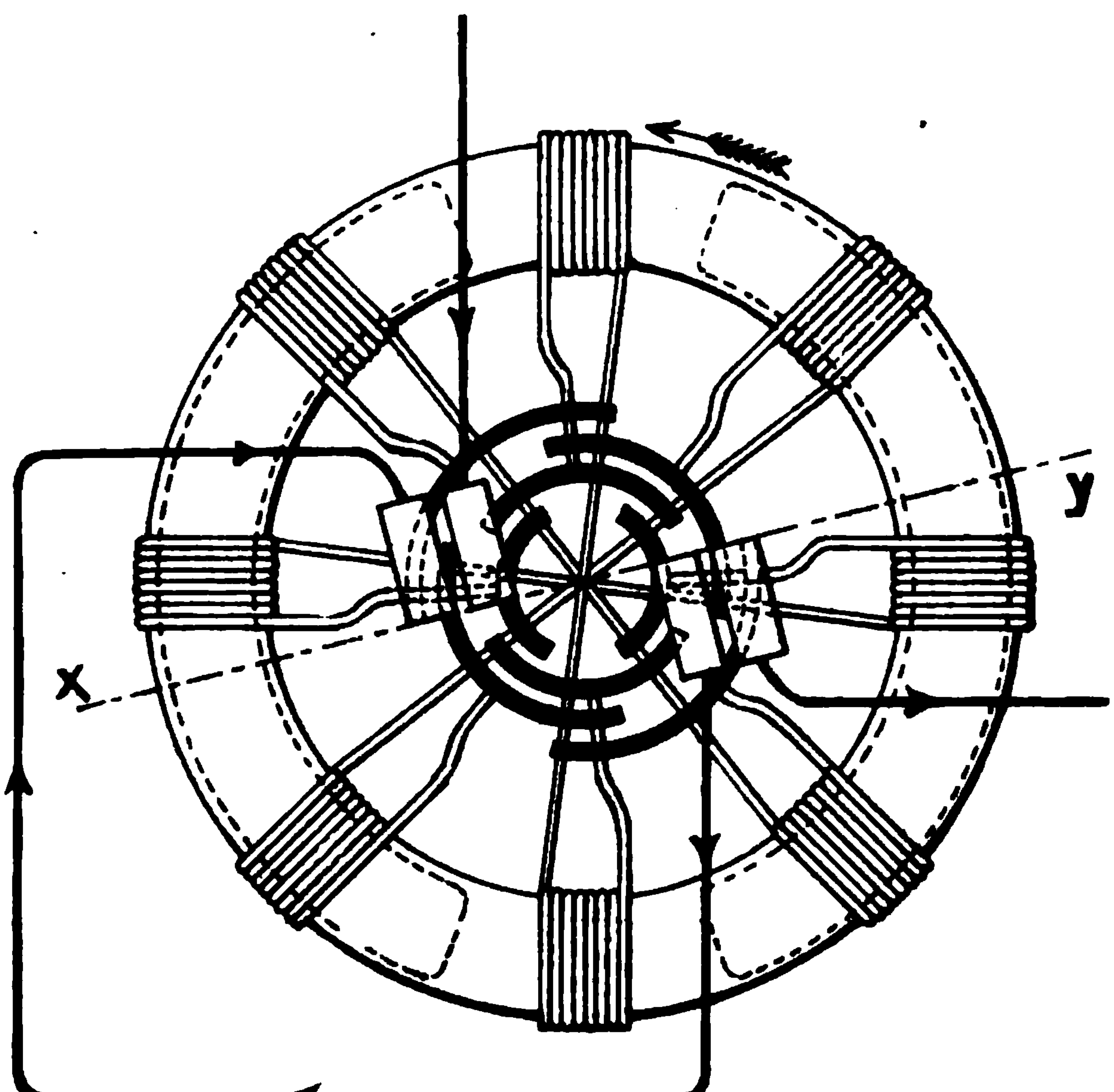


FIG. 53.

ings is maximum when that in the other is minimum the fluctuations are very much reduced by the series connection. The large size machines have three and four windings and commutators connected together in series, the same as the one shown. When the rotation is as indicated by the arrow, the line of maximum activity is on the line M M, and on this line the brushes make contact. During part of each revolution the brushes make contact with two segments, thus connecting two coils in multiple; when the brushes are on only one segment, only one set of coils is connected. The combinations in each winding during the rotation of the armature are: One set of coils alone, then two sets in parallel, then one set alone again, and so on continuously.

Regulation is accomplished by placing a resistance in shunt to the field coils. The resistance consists of a number of carbon plates or blocks, the resistance of which decreases when subjected to pressure. A magnet is in the main circuit, which, by means of a lever, exerts a pressure upon the carbon blocks, thus lessening their resistance and permitting more current to flow through them, thereby depriving the field coil of a corresponding amount of magnetizing current. By the reduction of the field strength the e. m. f. is also decreased. As more lamps are connected in circuit,' the resistance being increased, less current will flow, which causes the pressure exerted upon the carbon plates to be lessened, causing more current to flow through the field coils, thus increasing the e. m. f. There is some sparking, due to the weakening of the field, at light loads, which causes a shifting of the point of maximum activity, therefore the brushes must be shifted a trifle. In the multipolar machines this is done automatically by a device driven by a belt from the armature shaft, and thrown into or out of action by a controlling magnet connected in the main line.

The Wood arc dynamo has a ring armature of the closed coil type; the fields are of the bipolar consequent-pole type, four exciting coils being used. Four brushes are used, two positive and two negative. They are mounted on two rocker-arms, the leading positive brush being opposite the leading negative brush and the positive trailing or following brush is opposite the negative following brush. Shifting the rocker-arms not only shifts the brushes relative to their position on the commutator, but also changes their arc of contact, the span varying from about 3 segments at light loads to about 8 segments at full load. Movement is transmitted to the rocker-arms by pinions on the end of a shaft which is driven by a friction wheel, the teeth of the pinions engaging teeth in the rocker arms. The pinion that moves the trailing brushes being a little larger in diameter than the other it follows that, since both pinions are on the same shaft the trailing brushes move a little faster than the leading brushes, so that when their movement is backward the span of the two brushes on each side is increased, and is decreased when the brushes move forward. A pair of friction rollers is permanently driven by the armature shaft, one in opposite direction to the other. These are so mounted that either of them can drive the friction wheel which moves the rocker-arms, one of the rollers causing the wheel to turn in one direction and the other roller to cause movement in the opposite direction, so that the rocker-arm may move either forward or backward, as the load decreases or increases. The friction rollers are secured to a lever, actuated by the regulating magnets, in such a manner that when the

current strength is normal neither of them will be in contact with the friction wheel; a rise of the current strength, however, will cause the magnet to draw up the lever, thus allowing one of them to come in contact with the wheel and shift the brushes forward, which lessens the e. m. f. of the machine. A decrease of the current will weaken the pull of the regulating magnets and permit the adjusting spring attached to the lever to draw it down and cause the other roller to engage the friction wheel, causing the latter to turn in an opposite direction to the former one and by the resultant shifting of the brushes increase the e. m. f. of the machine. On the larger machines these rollers are driven by belt, instead of being geared to the armature shaft, but otherwise the action is precisely the same. The regulator can be adjusted to any current strength desired, within the limits of the machine, by the adjusting spring already mentioned.

The Western Electric arc dynamo also has a bipolar consequent-pole field magnet, except in the larger sizes, in which a multipolar field is used. The armature is drum-wound, and the regulation is effected by shifting the brushes by means of a mechanism driven by belt from the armature shaft, being thrown into or out of action by a controlling magnet as in the Wood machine. This magnet operates a reversible clutch arrangement which moves the brushes backwards or forwards as the load decreases or increases.

There are a number of other arc dynamos that possess considerable merit. Those described are most extensively used, however. Moreover, their status in modern electrical engineering does not warrant a further devotion of space to this class of machines.

The limiting factor of the output of these machines is the maximum e. m. f. the machine is capable of generating. When this has reached its highest point, an increase of load will, as it increases the resistance, only serve to decrease the current. Nearly all arc machines spark; however, as the current very seldom exceeds 10 amperes this sparking is of little consequence.

The heat losses are the same at all loads, since the current strength is always the same. In some of the open coils machines, however, a portion of the field winding is cut out of circuit to prevent excessive heating of the armature, which is caused by local currents in the coils, which may be greater than the current in the external circuit at light loads. The rating of constant current machines is usually stated in the number of lamps they can supply, since that is about the only use to which these machines are put. They have been built with a capacity up to 150 lights, but the sizes most in use are from 50 to 80 lights. As one arc lamp requires approximately 50 volts the e. m. f. of an 80-lighter would, at full load, be $50 \times 80 = 4000$ volts. The

voltage of a 150-lighter would be 50×150=7500 volts. Owing to these high voltages ring armatures are generally employed, since a burned out coil can be replaced without disturbing the rest of the winding.

Nearly all constant current machines require a careful setting and adjustment of the brushes to minimize the sparking. For this purpose the manufacturers supply a gauge with their machines which greatly facilitates setting the brushes in the proper position.

CHAPTER VI.

ARMATURE WINDINGS.

There are a great many different styles of armature windings and to describe them all would be beyond the scope of this book. Therefore, only those in general use will be discussed. Most armatures now-a-days, instead of being wound by hand, have form-wound coils; that is, the coils are wound on a form by machine. The coils are then bent to the required shape, wrapped with insulating tape, and placed in the armature slots. The insulation on the coils, however, is not entirely depended on to prevent contact between the winding and the core; in addition

FIG. 54.

thereto, troughs of mica, mica-cloth, or micanite, or other good insulating substance are placed in the slots before the coils are put in. After all the coils are in place the ends are connected to the proper commutator segments.

Bi-polar windings are such as are used on armatures for a bi-polar machine. The winding is divided into two circuits, whether the armature be drum or ring wound. Figure 54 shows a ring winding. The line N. N represents the neutral line, being a line at right angles to a line passing through the center of both

pole-pieces. Every armature coil passes the neutral line twice in each revolution. The neutral spaces are those parts of the armature in which the coils are cutting no lines of force, being a short space on each side of the neutral line. On this line the brushes are placed. The reason therefor will be explained later.

Multipolar windings are those used on armatures for multipolar machines. The bi-polar ring winding can be used in a multi-polar machine readily by making the number of brushes equal the number of poles, as shown by Figure 55, which

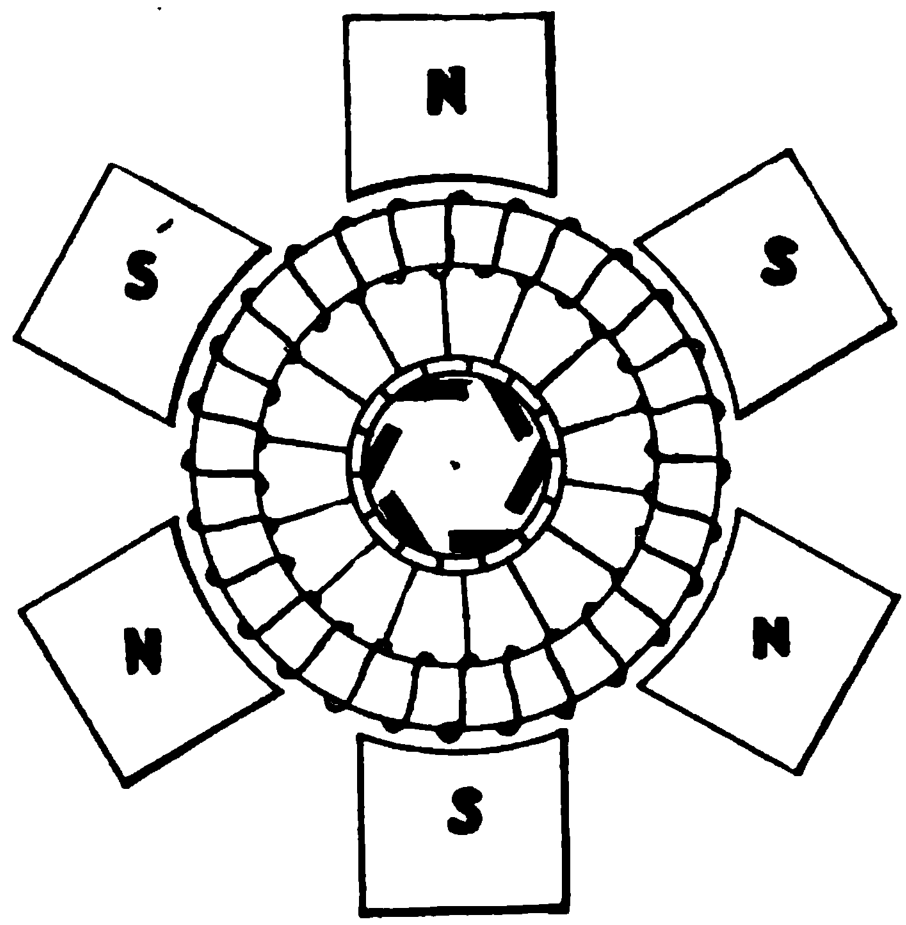


FIG. 55.

shows a ring winding for a six-pole field; there are as many circuits in this winding as there are poles, hence the six brushes. The six circuits are generally connected in parallel by connecting alternate brushes together, alternate brushes being of like polarity, and adjacent brushes of opposite polarity. The brushes must be so placed on the commutator that they make connection with each coil as that coil is passing through the neutral space. In such a multiple-circuit winding, if the number of lines of force between one pair of poles is greater than those between the other poles that portion of the winding which is passing through the stronger field will generate a higher e. m. f. than the other, and hence, take more of the load than it should. To avoid any chance of such a thing happening each coil can be connected in series with a coil in another field thus making a two circuit multi-polar winding, as shown in Figure 56, which shows a four-pole winding; the principle can be extended to suit any number of poles. But one pair of brushes are used, these being placed so as to be connected to coils which are in the neutral spaces. In multi-polar

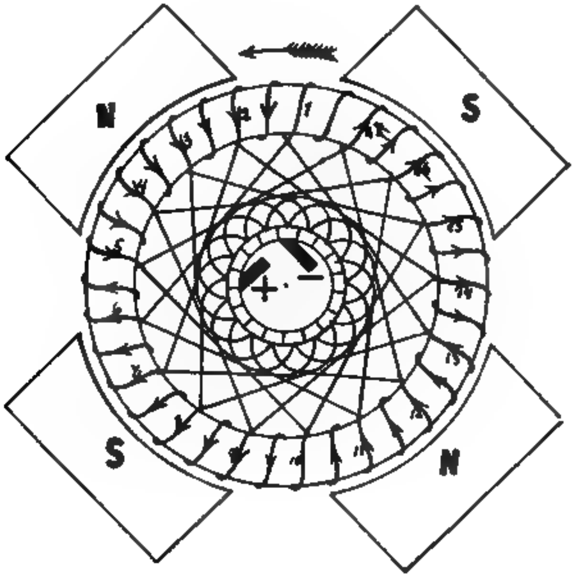


FIG. 56.

FIG. 57.

machines the neutral spaces are not diametrically opposite as in the bi-polar, but are midway between adjacent pole-pieces, regardless of the number of the latter.

Another form is shown in Figure 57, which is generally used for four-pole armatures. There are double as many commutator segments as there are coils and each end is connected to one segment and also to a segment diametrically across from it. This cross connection is usually made within the commutator instead of between lead wires as shown.

Drum windings are very inconvenient to represent owing to the difficulty of showing the back connections without a confusion of lines. Therefore the diagrams shown will have comparatively few coils; it should be understood that their number can be in-

FIG. 58.

creased as desired or necessary. As in the preceding figures the brushes are shown inside the commutator. The heavy radial lines represent the active conductors of the coils while the lighter lines show the scheme of connection. Each coil, therefore, consists of two conductors, the connection across the back and the connecting leads to the commutator. In large armatures the coils consist of single bars, but in the smaller ones a coil is usually wound of several turns, all the turns of course going into the same winding space.

Multi-polar Drums. Figure 58 shows a four-pole winding, as many brushes being used as there are poles. Such a winding is called a loop winding, since a tracing of same would form a succession of loops, and can be applied to any number of poles. Figure 59 shows what is called a wave winding, since the winding, going to front to back under one pole-piece and from back to front under the next pole-piece and to the back again under the following one and so on, forms a series of waves, instead of loops as in the former case. In this style of winding only two brushes are necessary, no matter how many poles there are in the field, since the winding is a two-circuit one.

FIG. 59.

Multiple Windings. Large machines, for heavy current output generally use two or more separate windings on the armature, these different windings being connected to their respective commutator segments, the segments for one winding being regularly interspersed between the segments of the other winding. By the use of a brush of sufficient width the several windings are connected in parallel. Each brush must therefore be wide enough to cover at least as many segments as there are different windings. Such windings are called multiple windings; they may be ring or drum-wound; either two-circuit or multiple-circuit; in the latter case using as many brushes as there are poles, and in the former case but two brushes are needed, no matter what the number of poles.

CHAPTER VII.

ARMATURE REACTION.

It has been stated that an electric current flowing in a conductor sets up a magnetic field around the conductor, and that the strength of this field is proportional to the strength of the current. Now let us consider the conductors on an armature. They lie in the magnetic field produced by the field coils. When the machine is under load a current is flowing in them, setting up a magnetic field of its own, the strength of which is dependent on the strength of the current in the armature. This magnetism affects the field magnetism, distorting it from its natural path, so that it no longer travels from the N pole straight across to the S pole. Figures 60 and 60a show the path of the magnetic

FIG. 60.

FIG. 60a.

lines with and without current flowing in armature. We see that in the first case, where no current is flowing, the neutral line n n is exactly at right angles to a line through the center of both poles, whereas in the second case, where current is flowing in armature, the neutral line is shifted several degrees ahead due to the distortion caused by the current in the armature. This distorting effect increases as the current increases. When current flows in the armature, consequent poles are produced at the coils connected to the segments where the current enters and leaves. This is shown in Figure 61, which is a diagram of an armature re-

FIG. 61.

moved from the machine. The consequent poles are directly in line with the brushes. When the armature is put in place again the consequent poles are shifted around some against the direction of rotation, due to the effect of the field magnetism. The tendency of the latter is to pass straight through the armature and into the opposite pole, and the tendency of the magnetic lines in the armature core, due to the current in the winding, is to pass out at the botton and enter again at the top. The two fluxes are therefore almost at right angles to each other; however, since magnetic lines can never intersect, each flux will be distorted from its original direction, with the result that the consequent poles of the armature core are shifted backwards, and the field is dragged forward, that is, in the direction of rotation, hence, also, the neutral line is shifted forward. The effect is the same with either drum or ring wound armatures. As long as

the brushes are on the neutral line the magnetism of the armature, being at right angles to the field, only distorts the latter. As soon, however, as the brushes are shifted forward, to obtain sparkless commutation, the consequent poles of the armature are also shifted, resulting in their opposing the field, thereby weakening the latter. There are really two magnetic forces acting in the armature, one at right angles to the field, hence, distorting it, and the other weakening the field because it is acting in direct opposition thereto. Owing to these effects of the armature magnetism upon the field, the latter is made very strong as compared to the former.

Another effect of the current in the armature conductors is the drag produced upon the latter by the reaction of the field magnetism upon them. When no current flows in the armature it requires very little effort to turn the armature. As soon, however, as a load comes on and current flows, the force necessary to keep the armature moving must be correspondingly increased. Whenever a conductor lying in a magnetic field is carrying a current, that conductor will tend to move, and the strength of this moving tendency will depend, with given field strength, directly upon the strength of the current in the conductor, and the direction of motion will depend on the relative direction of the current and the lines of force. Figure 62 shows a conductor lying in a

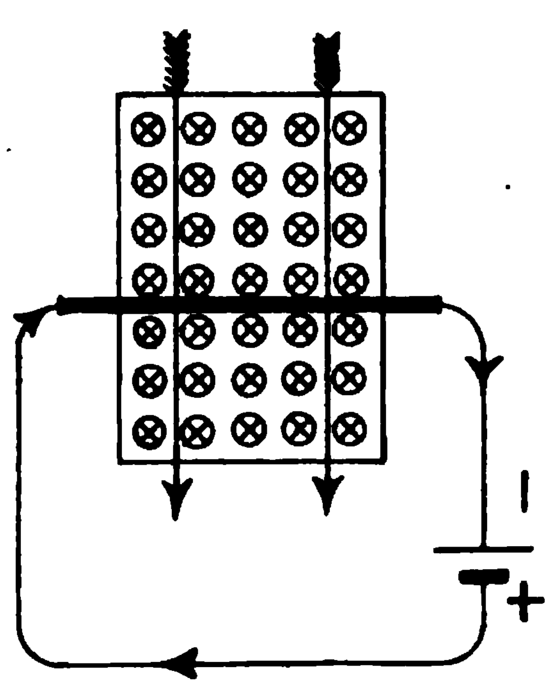


FIG. 62.

magnetic field, the direction of the lines being downward, or piercing the paper, the current in the conductor being as shown by the arrowheads; the conductor will tend to move to the left, as shown by the arrows, or opposite to the direction in which the conductor would have to be moved in order to set up an e. m. f. in it. A convenient way to establish in one's mind the relations between the direction of the lines of force, the direction of current in a conductor lying in said field and the direction of its

tendency to move, is to place thumb, fore and middle fingers of left hand in such shape that they will be at right angles to one another, see Figure 63; if the fore finger points in the direction of the lines of force, that is, toward the S pole, and the middle finger points in the direction in which current is flowing, then the conductor will tend to move in the direction indicated by the thumb. Consider the conductor as a coil on an armature driven so it will move from left to right, the induced e. m. f. will be upwards, and when the circuit is closed current will flow. As soon

FIG. 63.

as this occurs the conductor will experience a pull or drag upon it that will tend to move it in the opposite direction, and the strength of this pull will depend directly upon the strength of the current flowing. Of course this counter-force, being a product of the moving force, can never exceed, or even equal the latter, but it exerts a drag upon the conductor, thereby greatly reducing its speed and necessitating an increase of driving force. By far the greatest part of the mechanical energy delivered to the pulley of a dynamo is expended in overcoming this counter-torque, as it is called; torque meaning turning force.

CHAPTER VIII.

COMMUTATION AND SPARKING.

The shifting of the neutral line already explained, affects the commutation of current, because, if the brushes are on segments connected to a coil lying in the magnetic field bad sparking results. Since the coils are each connected to two adjacent commutator segments, it follows that each coil is short-circuited as the segments to which it is connected pass under a brush. Therefore commutation must take place at the instant that the coil is in the neutral space, as in that position no e. m. f. is being induced in the coil and, therefore, short-circuiting the coil at that instant will not produce any spark, there being no current to produce it. At this point a reversal of current takes place in the coil. Just before a coil reaches a neutral space the e. m. f. in it is acting, say upward, but decreasing in value, and at the instant it passes the neutral space it cuts no lines of force, hence is generating no e. m. f. Therefore it may safely be short-cirucuited at this point. From this it is clear that a shifting of the neutral line necessitates a shifting of the brushes, since if this were not done, evidently commutation would take place while the coil is still generating a considerable e. m. f., and bad sparking would result. As soon as the coil enters the opposite field the e. m. f. induced in the coil will be in an opposite direction to the former one, on account of its cutting the lines of force in an opposite direction. Sometimes the brushes are so set that the commutation does not take place until the coil has already entered the opposite field, hence has the e. m. f. in it already reversed and rising in the opposite direction. Although a coil as it passes through the neutral space has no e. m. f. generated in it, it must nevertheless carry the entire armature current. The direction of the current in the coil is reversed at the instant that both its segments are under one brush; as soon as the forward segment passes from under the brush the coil has passed from one circuit to the other wherein the current flows in an opposite direction. Now as an armature coil is a coil of wire with an iron core, it possesses considerable inductance, and, owing to this inductance, the current in the coil does not cease entirely the moment the coil is short-circuited by the brush, but continues to flow in the local circuit of the coil, segments and brush, being kept up by the e. m. f. of self-induction of the coil. Also, when the forward segment leaves the brush the inductance prevents the armature current (which must then flow through the coil which was short-circuited) from at once rising to full value, resulting in a portion of the current going from the segment to the brush across the small air-space between the latter and the retreating segment, causing a spark. As soon as the e. m. f. of the armature overcomes the effect of the inductance of

the coil more current will flow through the latter, being aided to do so by the increasing resistance of the widening air-space between brush and segment. The spark therefore becomes rapidly less, finally ceasing entirely. As the armature is moving at a considerable speed, however, the one spark will not yet have disappeared when another has started, due to a repetition of the process already described, by the following coil. Therefore the sparking appears continuous. As this sparking is very destructive to both commutator and brushes it is desirable to get rid of it. By letting the coil get into the new field, before it becomes short-circuited by coming under the brush, the current in the coil will not only be brought to zero, but, by bringing it into a sufficiently strong field to generate an e. m. f. greater than the e. m. f. of self induction of the coil, the current will be reversed in direction, and if commutation takes place at the instant when this reversed current has reached the same value as that flowing in that part of the armature into which the short-circuited coil will be connected as its segment leaves the brush, no sparking will occur. Should the value of this current be less than that which it will have to carry, a slight spark will occur, which, however, will be considerably less than if the coil were short-circuited before the current in it had been reversed. If the current is allowed to rise to a greater value than that in the balance of the armature before commutation takes place, since the entire current in the short-circuited coil will tend to keep on flowing for an instant, there will be a spark across the air-space between brush and forward segment as the latter moves out from under the former. The remedy in either case is easy enough; all that is necessary is to shift the brushes a little, either forward or backward, as may be required, the brushes being mounted to readily permit this shifting within a large range. Shifting them away from the neutral line in the direction of rotation is called giving them forward lead, while the reverse is called backward lead. The amount of lead is greater at heavy loads than at light loads, the distorting effect of the greater current in the former case being stronger than that of smaller currents. As there is no precise point at which the neutral spaces end or begin, it is not hard to find a point of sparkless commutation for any load if the machine is otherwise all right. The magnetic fringe at the tip of the pole-piece decreases gradually as we approach the neutral line, being zero at the latter point. As sparking is a direct result of the inductance of the coils and the inductance of a coil varies as the number of its turns (other things being equal) we easily recognize the advantage of having the coils small and of few turns, (in order that the inductance be kept as low as possible) and increasing the number of coils. Another strong factor, where carbon brushes

are used, is brush and contact resistance. Carbon brushes have a comparatively high resistance, and the contact resistance is constantly increasing as the area of the brush in contact with the retreating segment diminishes. This resistance at the point of contact sets up a difference of potential between the brush and the segment, which helps to reverse the current in the coil, and if it could be made great enough would prevent sparking just as effectually as shifting the brushes does. This method is never used alone; however, it is very useful as it reduces the amount of shifting of brushes necessary for a given change of load. The effect of brush and contact resistance is very small where metal brushes are used, owing to their low resistance. Most machines now built, however, require no shifting of brushes for any change of load, from no load to full load. As the machine is overloaded the neutral spaces advance farther and hence the brushes must also be given more lead. Now as the current in the armature tends to weaken the field, evidently there is a point at which we can not get a sufficiently strong magnetic fringe to reverse the current in the coil and bring it up to the required strength to obtain sparkless commutation. This is called the sparking limit and is one of the factors that limits the output of a machine.

CHAPTER IX.

DIRECT CURRENT MOTORS.

The action of an electric motor is based on the fact that when a conductor is lying in a magnetic field, at right angles to the direction of the lines of force, the conductor will tend to move as soon as current flows through it. The strength of the moving tendency depends upon both the intensity of the field and the current, while the direction of the motion of the conductor will depend upon the relative direction of the lines of force and the current. Therefore, in order to reverse the direction of motion of the conductor it is necessary to reverse either the field or the current flowing; reversing both the current and the field at the same time would cause no change in the direction of motion of the conductor, since the relations between field and current would not be altered.

There is no essential difference between a motor and a generator, since one machine can be used for either purpose. For some classes of work, however, special types of motors are built whose details and construction differ materially from those of generators or other types of motors. These changes do not affect the principle of their operation in any way, but they serve to better adapt the machines to the service for which they are built. For instance, railway and crane motors are built very compact, so

as to take up the smallest amount of space, their poles are very short and the commutators and bearings are smaller; the former are also made water and dust proof. Figure 64 shows a typical street railway motor.

Others are built so that they may be fastened to a wall or suspended from the ceiling, these being generally of the enclosed or semi-enclosed type, as they are frequently installed where there is a good deal of dirt flying around. They are only made in the

MOTOR CLOSED.

MOTOR OPEN.
FIG. 64.

smaller sizes. The regular forms of stationary motors present the same appearance as an ordinary generator.

Motors are connected to the line in parallel or multiple. That being the case it is necessary to explain why the armature is not burned out by an excess of current when it is subjected to the line voltage, as its resistance is very low. The reason that this does not occur lies in the generator action of the revolving armature.

Whenever an armature is revolved in a magnetic field e. m. f.'s are set up in the armature. It matters not whether the motion is obtained from a belt, engine, water-wheel or any other prime mover, or whether the movement is due to a current sent through the armature from some other source, as in the case of a motor; the effect is the same. The strength of the induced e. m. f. is, as we have already learned, proportional to the speed, with any given armature and field; its direction will be opposed, or counter to the direction of the current which produces the motion, hence, will endeavor to stop the flow of current. Its force is therefore called the counter-electro-motive-force of the armature, usually abbreviated c. e. m. f. If a motor could be built to run without any frictional or other losses and this motor were connected to a

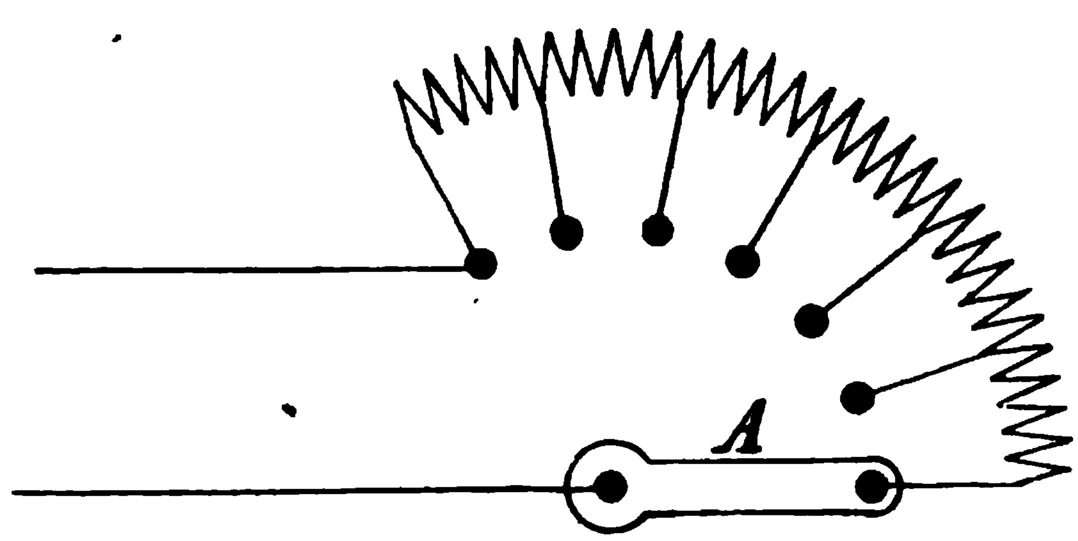


FIG. 65.

supply circuit and run without any load, its c. e. m. f. would, when the armature had attained its normal speed, equal the e. m. f. of the line and no current would flow through the armature. However, as no machine can be built which has no losses, the c. e. m. f. will always be lower than the line voltage, the amount of this difference depending, with any given motor, upon the amount of work performed by the motor. Therefore the current strength in the motor will always be proportional to the load. But why does not the motor burn out when it is started before it can attain sufficient speed to generate the necessary c. e. m. f. to check back all but the current required to do the work imposed on the motor?

To prevent the possibility of such an occurrence a resistance, called a starting box, is connected in series with the armature. By means of the movable arm A, Figure 65, the resistance of the starting box can be cut in or out of circuit step by step. This re-

sistance prevents an excessive rush of current on starting; as soon as the motor has started, the arm is moved to the second contact point, being left there a second or two, and then moved to the next and so on until the resistance is all cut out, the increasing speed of the motor constantly increasing the c. e. m. f., which will compensate for the reduction of the resistance.

The tendency to rotate which a motor possesses when current is flowing through it is called the torque. When the torque is greater than the opposition to motion the armature will revolve and the speed will rise until the opposition to motion and the torque just balance each other, at which point the speed will remain constant until there is a change in the load. If the load is now increased the speed will be reduced, which causes a reduction of the c. e. m. f., thus permitting more current to flow and increasing the torque until it again balances the load. Decreasing the load causes the speed of the motor to rise, increasing the c. e. m. f., resulting in a reduction of the current through the motor, thus reducing the torque, which reduces the speed. From this it would seem that there would be a considerable variation in the speed of a motor under varying loads. This is not the case, however, if the field strength be maintained constant. As already stated, the resistance of the armature is kept as low as possible, as the higher the resistance the greater will be the drop with any given current. This drop is a waste of energy, therefore it is not wanted. As the difference between the c. e. m. f. and the line voltage always equals the drop in the armature, it follows that small variations in speed will give great variations in current, as will be seen from the following example. A given armature has a resistance of .5 ohm, and the motor is connected to a 500 volt circuit; a current of 25 amperes is flowing, hence the drop will be $25 \times .5 = 12.5$ volts. The c. e. m. f. therefore is $500 - 12.5 = 487.5$ volts. We now reduce the load 80 per cent so that only 5 amperes are flowing; the drop will then be $5 \times .5 = 2.5$ volts, and the c. e. m. f. will be $500 - 2.5 = 497.5$ volts. The current therefore varies 80 per cent and the c. e. m. f. only varies

$$\frac{497.5 - 487.5}{487.5} = \frac{10}{487.5} = .0205 \text{ or a trifle over 2 per cent.}$$

so that for a load variation of 80 per cent the speed variation is only 2 per cent. The speed is entirely dependent on the e. m. f. applied, or, strictly speaking, to the c. e. m. f., and does not necessarily vary the torque, though it may do so under certain conditions. The torque is a matter of current only, that is, under similar conditions, the torque will be proportional to the current flowing, regardless of the speed. As already explained, the torque adjusts itself automatically to changes of

load, being caused to do so by the variations of the current due to a variation of the speed and c. e. m. f. The speed can be varied at will in various ways, which are described farther on.

Commutation occurs or should occur back of the theoretical or neutral line, (instead of ahead of it as in a generator) the shifting of the latter due to field distortion being against the direction of rotation, therefore the brushes are given a backward lead. The brushes on some motors are fixed in the correct position, no shifting being necessary for any change of load within the limits of the machine.

Motors may be either shunt, series or compound wound though they are never connected in series with the line.

The shunt motor is used where the load is so arranged that the motor can start without load and where a practically constant speed is desired at all loads. Since the field coils are connected directly across the line it follows that the field strength is constant irrespective of the current flowing in armature, except in so far as the latter demagnetizes the field, owing to the backward lead of the brushes. Therefore the motor will tend to run a trifle faster with increased load due to the greater weakening effect of the increased armature current upon the field. This tendency makes the shunt motor virtually automatic in regulation for all changes of load.

Further consideration will also show why this type of motor is unsuited for starting under load. As its field strength is practically constant, and therefore also its torque for given armature current, and since it requires a greater effort to start a load from rest than to keep it going after it is started, it follows that this extra effort would have to be produced by the armaure alone, requiring an excessive flow of current. This excessive current would of course weaken the field considerably, thereby reducing the torque and necessitating a still greater current in the armature, which would still further weaken the field. Figure 66 is a diagram of the connection of a shunt motor and a starting box. These connections are very frequently made wrong and then the man that connected the motor up wonders why the machine behaves so mulish. The most frequent mistake is connecting the field across the brushes instead of making the connection as shown. The result is that the field winding gets only the reduced pressure supplied to the armature owing to the drop of the starting box. When the connections are properly made, however, the starting box is in series with the armature only, the field getting the full line pressure. In the figure M is a small magnet connected in series with the field winding. This magnet holds the lever against the pull of the spring S when current is flowing, a plate of soft iron, A,

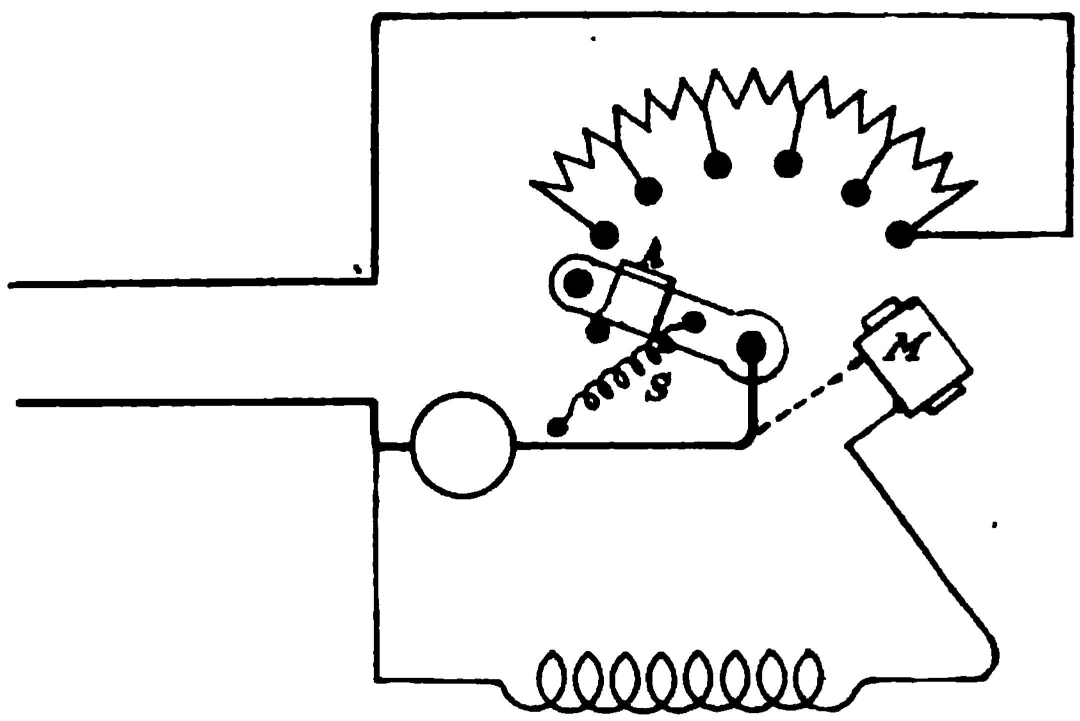


FIG. 66.

secured to the lever being the armature of the magnet. The function of this arrangement is to cut in the resistance automatically in case the current is interrupted from any cause. Were the flow of current to stop evidently the motor would stop also and then, should the current come on again before some one had set the starting box handle to the starting position, there would be such a rush of current through the armature as to very likely damage it. This danger is eliminated by the "automatic release" starting box, as it is called. The reason for connecting the release magnet in the field circuit is so that it will operate also in case the field circuit should become broken, which would also permit a rush of current through the armature, as the latter could then, owing to the absence of field flux, generate no c. e. m. f. Some starting boxes are made with combined overload and no-voltage release. These sometimes have the release magnet wound with a fine winding which is connected in the field circuit, and a coarse winding connected in series with the armature, the two windings being so wound that the flux produced by the one counteracts that produced by the other. As long as the current in the armature is normal the magnet will hold the lever. As soon, however, as it rises beyond normal strength the coarse winding on the release magnet will overpower the fine winding and the lever will fly back to the starting position. The objection to this type is the impracticability of adjusting the point of release. Another type has a second magnet, energized by the armature current, which acts on a pivoted armature drawing up the latter when the current rises beyond a predetermined value. This point can be varied by the adjusting screw S, Figure 67, F being in series with the field and A in series with armature. When A pulls up its armature, against the pull of the spring S, evidently magnet F will be short-circuited, causing the lever to fly back to the starting position. With an automatic release starting box there is a decided objection to having the connections as shown in Figure 66, as, when the

lever flies back to the starting or off position the field circuit is thereby opened. This produces momentarily a high e. m. f. of self-induction in the field winding far in excess of the normal line voltage, which is liable to puncture the insulation. To prevent this occurrence the two schemes shown in Figuse 68a and Figure 68b are resorted to, A being the more common; R is the release magnet in each case. It will be noticed in diagram R the field coil is always connected directly across the line, whereas in A the field coil is directly across the line only when the starting lever is on the first point, the resistance being in series with the field when lever has reached the last or running position. This does not materially affect the operation of the motor, however, because the drop through the resistance with the small amount of current required by the field is low enough to be negligible. The field, and therefore also the torque, is strongest at the start, when it is most

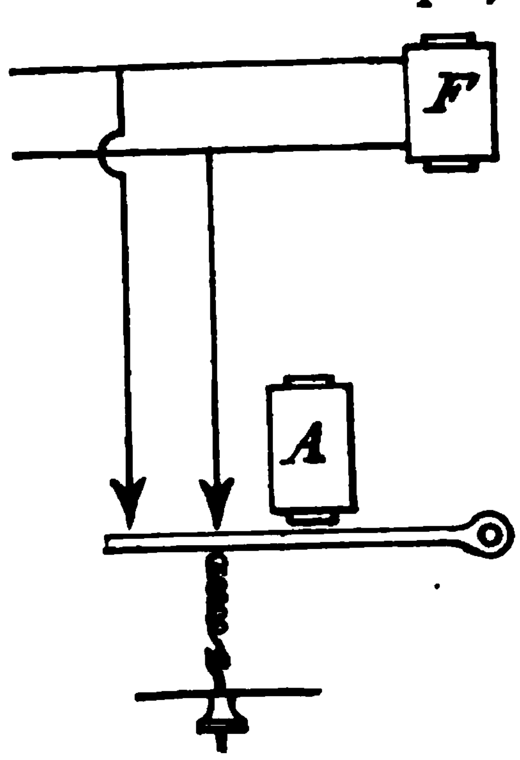


FIG. 67.

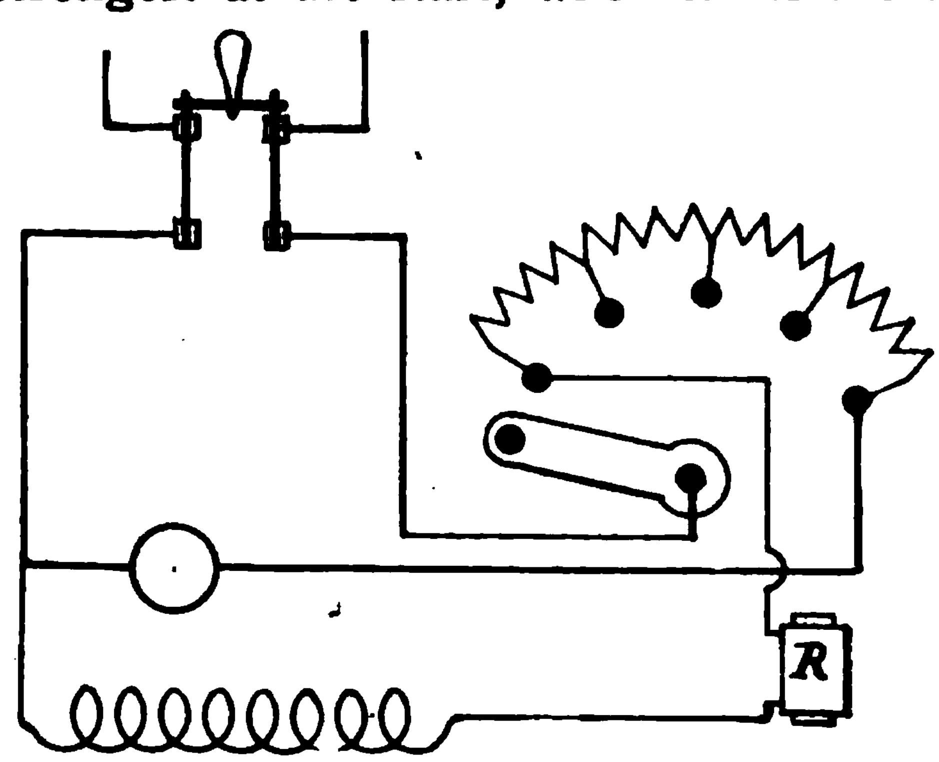


FIG. 68a.

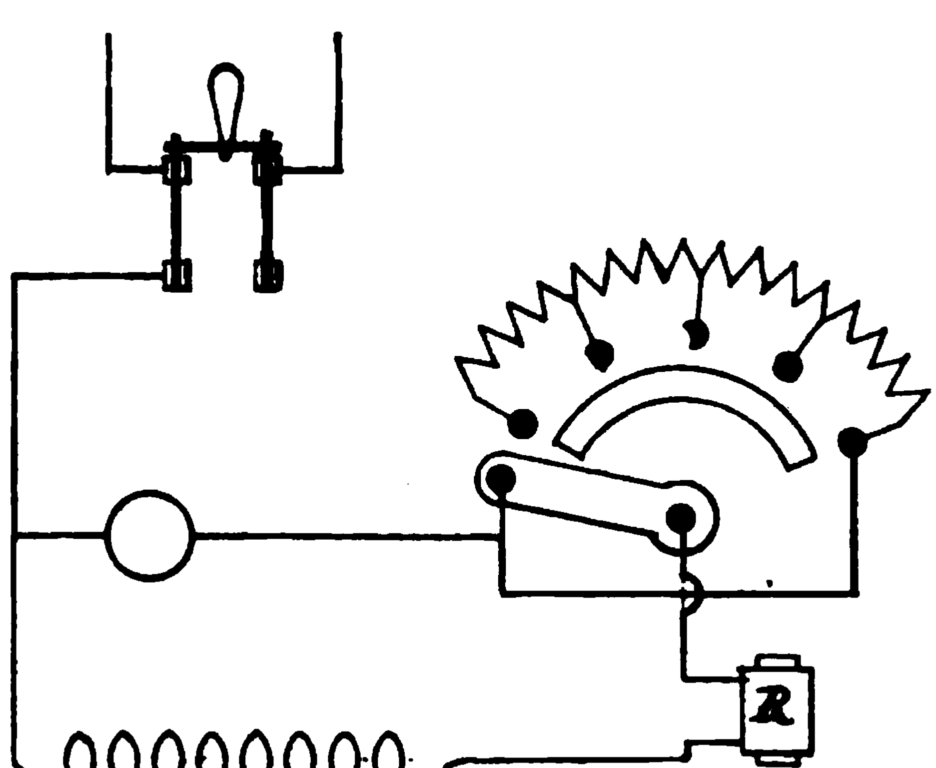


FIG. 68b.

needed. On some makes of starting boxes there is a contact button between the off position and first or starting position, this button being dead. The service performed by this button is the breaking up of the spark between the lever and the last live contact button on opening the circuit.

The series motor is used wherever it is necessary for the motor to start under load as, for instance, on street cars, elevators, cranes, etc. The field coils consist of comparatively few turns, as compared to those of a shunt motor. The field winding must be large enough, however, to carry the total current required by the motor, as starting box, armature and field coils are all in series with one another, as shown by Figure 69. The field being

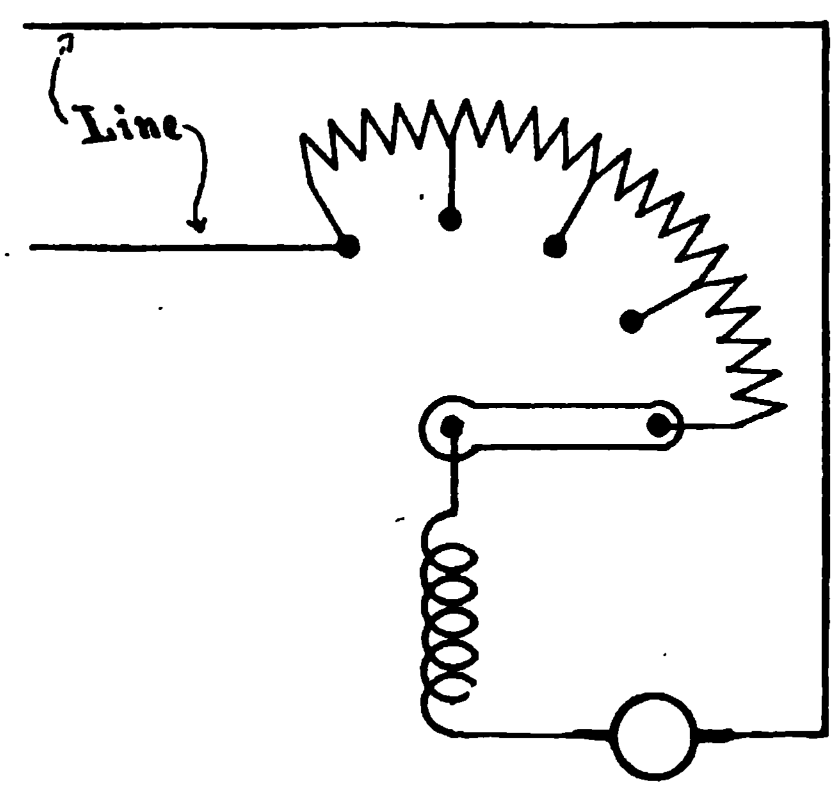


FIG. 69.

in series with the armature evidently the field magnetism increases with load and therefore the torque also varies with the load. On starting, when the strongest torque is needed, the current will be above normal, hence, also the torque, and the latter is able to overcome the load's opposition to motion. As the speed increases the c. e. m. f. cuts down the current and reduces the torque, an excess of which is no longer needed, once the load has been brought up to speed. Now here comes the disadvantage of the series motor. Since the weaker the field the faster the motor must run to generate the proper c. e. m. f. to cut down the current to amount required to carry the load on the motor, and since the strength of the field is proportional to the current flowing, it follows that, as the current required to run the motor without load is very small, taking off the load will decrease the field strength, thereby compelling the motor to greatly increase its speed to generate sufficient c. e. m. f. to cut down the current to the proper value, and as every reduction of current results in a corresponding reduction of field strength, the speed of the motor would keep

increasing, or as it is called, the motor would race or run away. For this reason as well as from the requirements of their work series motors are generally under the control of an operator or motorman, as frequent starts, stops and reversals are required.

Motors can also be compound wound, just as generators, which is sometimes, though infrequently done. The object is to get the advantages of the shunt motor relative to constancy of speed under all loads and the advantage of a series motor with its strong starting torque. The field strength due to the shunt winding preventing the motors speeding up as a load is removed. The connections are shown in Figure 70, in which A is the armature, S the series field coil and s the shunt field coil. The series field coils are connected across the last two contacts on the starting box in cases where the compounding effect is wanted only to assist in starting the load. When the compounding effect is wanted continuously the connections are as shown in Figure 71.

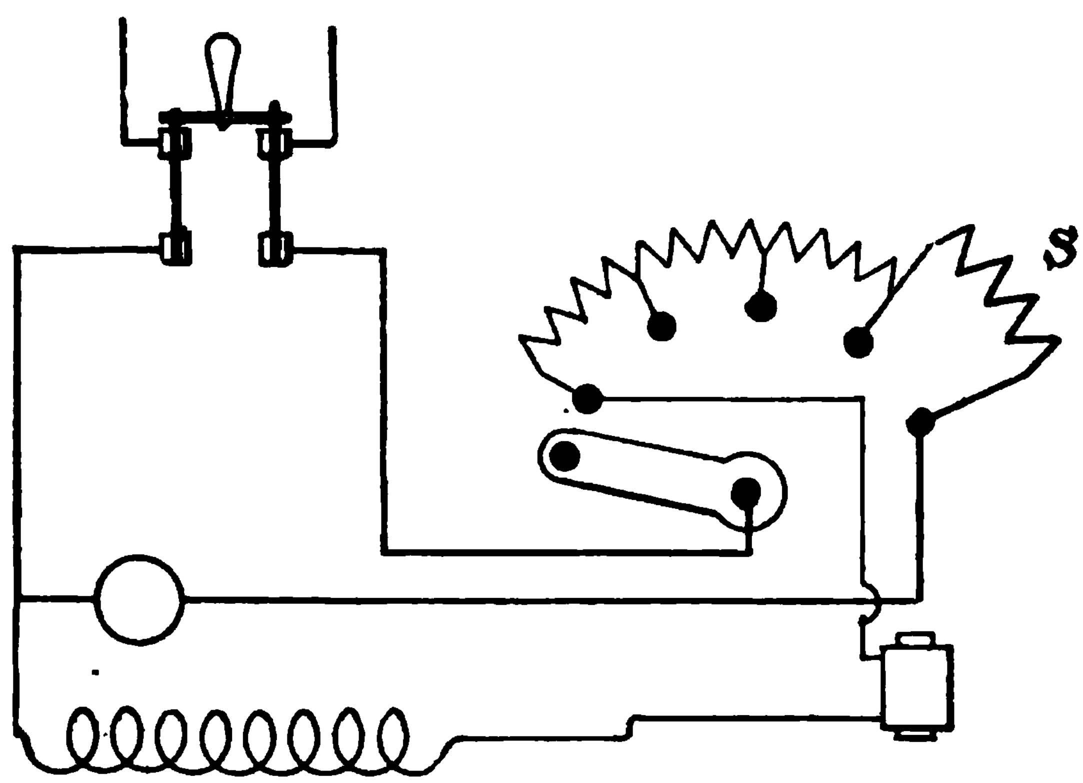


FIG. 70.

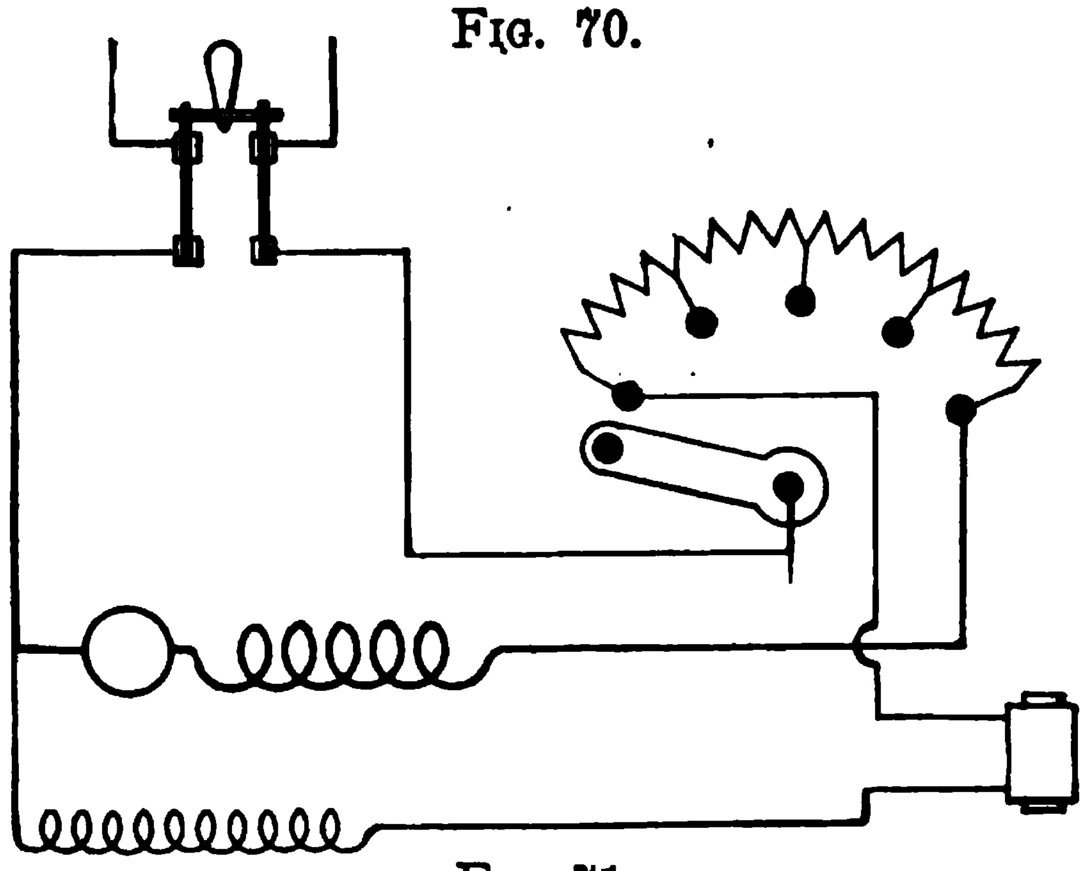


FIG. 71.

CHAPTER X.

MOTOR SPEED CONTROL.

For some classes of work it is desirable, even imperative, that the speed of the motor can be varied at will, as for instance, in motors used to drive vehicles, lathes, planers, milling machines, printing presses, etc., as the different operations of such apparatus require various degrees of speed. There are a number of ways of attaining the desired end, some very elaborate; probably the most elaborate and complex being the Sprague Multiple-Unite-System, a description of which would carry us beyond the scope of this book. Those interested can find a complete description and diagrams of connections in Nos. 1-5-6 and 8 of Volume 13 of the American Electrician.

The simplest method is varying the resistance of the armature by the insertion of a resistance which can be cut in or out by a controller, thus varying the effective e. m. f. at the machine. This resistance must be of sufficient cross-section to carry the entire armature current; the ordinary starting box would not do, as that is intended to be in circuit for a short time only and would be burned out in ten minutes, or perhaps even less time.

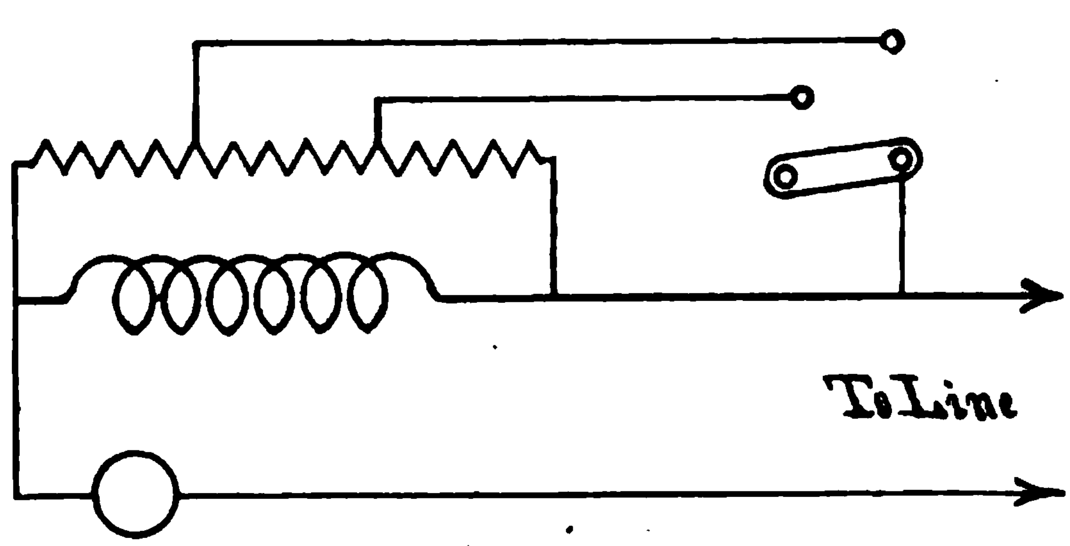


FIG. 72.

As this arrangement is wasteful it is not generally used. The effect of the current through the resistance is to heat the latter, which is an expenditure of energy.

Another system is to weaken the field to increase the speed which can be done, in a series motor, by placing a resistance in parallel with the field winding and by varying the former it will deprive the latter of more or less current, thus varying the speed; the scheme is shown diagramatically in Figure 72. In the case of a shunt motor the resistance should be placed in series with the field winding to weaken the field strength, as shown by Figure 73. This method is not as wasteful as the first one, but there is a comparatively narrow limit to the possible speed variation. Where greater variation is desired it is usually obtained by having lines

of different voltages, the motor being connected across the low voltage line for slow speed and across the intermediate for medium speed, the full speed being obtained by connecting to the high voltage line: By the use of several voltages as many different steps can be obtained. If in addition thereto one of the

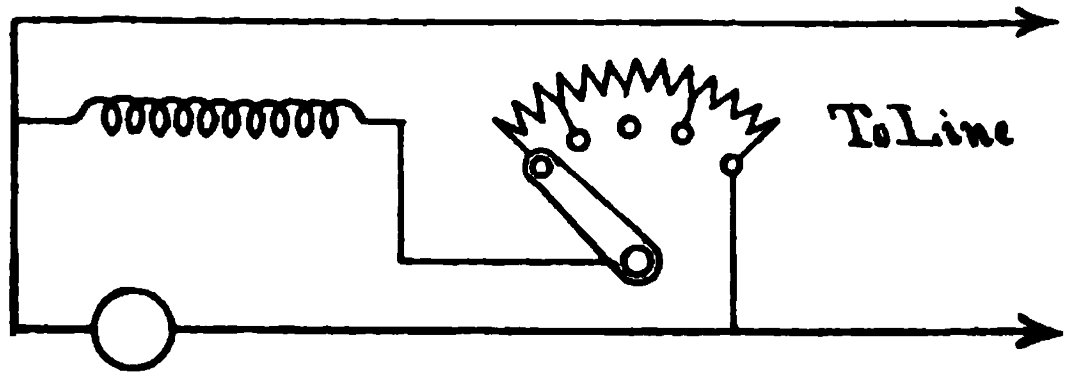


FIG. 73.

foregoing methods of speed control is also used, any degree of speed can be obtained without much waste of energy by the heating of resistances. The different voltages are obtained as shown in Figure 74, in which G is the generator and E E E are the armatures of three shunt wound generators connected together mechanically by couplings on their shaft. Such an arrangement

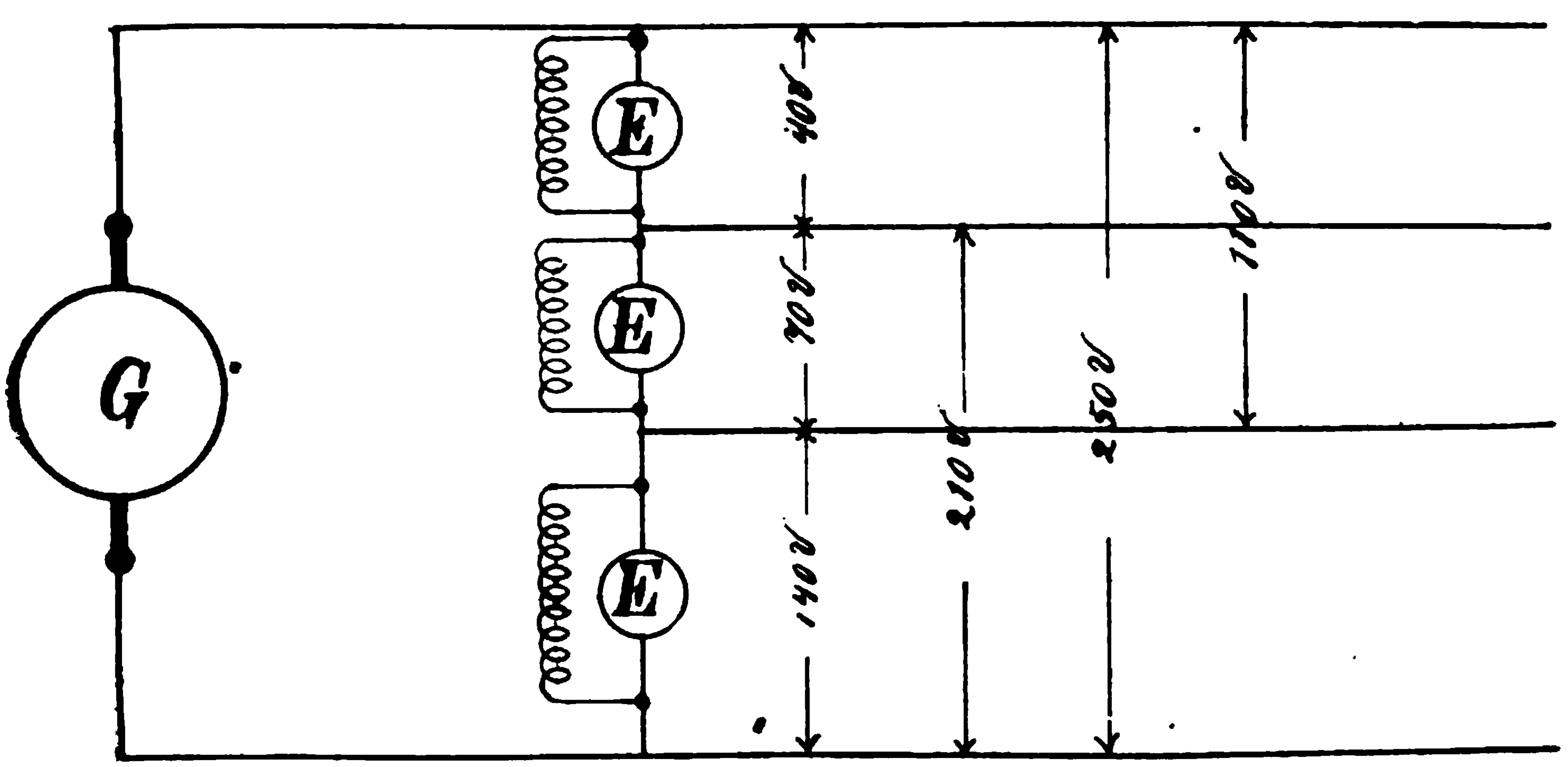


FIG. 74.

is called a motor-balancer or an equalizer set. The three armatures are connected, electrically, in series and lines are run out to the motors as shown. In the diagram the voltage of the first armature is 40, that of the second 70, and that of the third 140 (although any other values could be used as well, as long as their sum equals the generator voltage) the sum of the three being

250, which is the generator voltage. By the use of a suitably arranged controller the motors can be connected across the various wires, resulting in six different combinations and voltages, viz:

Between wires Nos.	one and two....	40	volts.
" " "	two and three...	70	volts.
" " "	one and three...	110	volts.
" " "	three and four..	140	volts.
" " "	two and four....	210	volts.
" " "	one and four....	250	volts.

This arrangement is also used where both lights and motors are to be fed from the same generating unit and it is desired to run the motors at a higher voltage than the lights. Only two machines are used usually, unless motor speed control is also desired at the same time, the voltage of one being that at which it is desired to burn the lights and that of the second being the difference between the first and the generator voltage. Evidently the motor-balancer need not have the same capacity as the generator, since the latter carries part of the load direct, but the determination of the proper size of the former requires a close study of the conditions under which it is to operate. It is well to remember that it is less expensive to install one of somewhat greater capacity than needed than to take out one that is too small.

Where two motors run together, as for instance on a street car, they are generally controlled by what is known as the series parallel system. The resistance coils are under the car and taps are taken from their different sections to the controller.

The connections are as follows:

1st point: Motors in series with each other and all the resistance.

2d point: Motors in series with each other and half the resistance.

3d point: Motors in series, all resistance cut out.

4th point: Motors in series, all resistance cut out and fields shunted.

FIELDS FULL STRENGTH.

5th point: Motors in series, half the resistance in circuit.

6th point: One motor in series with half the resistance, other motor cut out.

7th point: One motor in series with half the resistance, other motor cut out.

8th point: Both motors in parallel in series with half the resistance.

9th point: Motors in parallel, all resistance cut out.

10th point: Motors in parallel, all resistance cut out and fields shunted.

Figure 75 shows such a controller; the movable part is of circular form and for convenience is shown as if it were rolled out. The contract strips are bent into circular shape and are fastened to the movable cylinder, their position on the latter determining at which notch they shall make contact with the stationary contact fingres shown on the left, and their length determining during how many points they are to remain connected. On the right hand side of the top is a smaller cylinder which can be moved to right or left, (it is now in the off position); this is

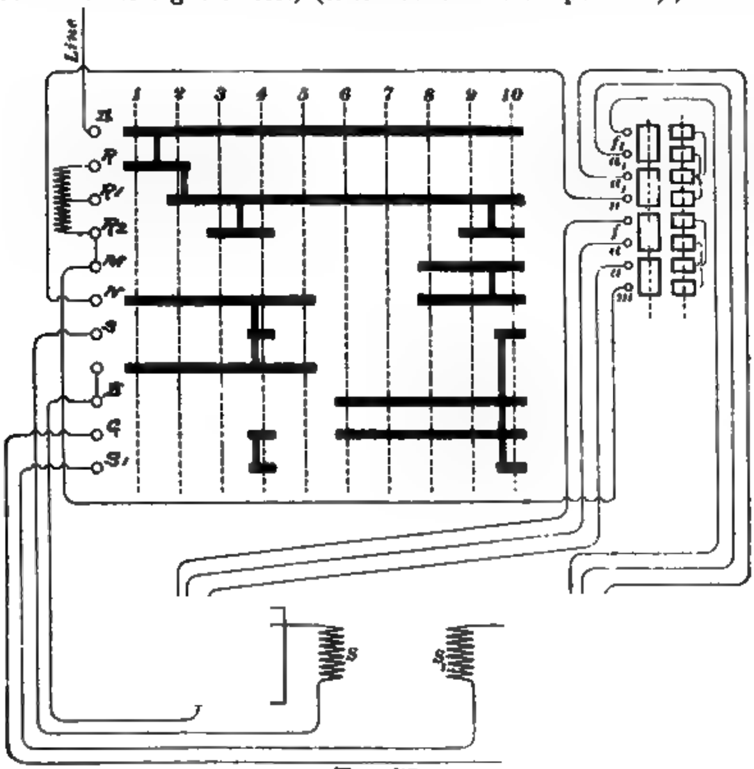


FIG. 75.

the reversing switch and by tracing out the connections it will readily be seen how the relative direction of armature and field current is reversed. There is an interlocking device on this controller which prevents the reversing switch from being moved except when the controller is in the off position. This prevents reversing the motor when there is current flowing through it. Should a motor be reversed while it is running, the reversed line e. m. f. would then act in the same direction as the

c. e. m. f. of the armature and the result would be such a tremendous rush of current through the motor, that the resultant force would stop the armature and try to start it in the opposite direction so quickly that it would very likely strip the teeth off the gear or pinion which transmits the motion of the armature to the car. Moreover, the controller cannot be moved while the reversing switch is in the off position. As street cars require fairly heavy currents, and the breaking of a circuit carrying a heavy current results in bad flash or arc at the break, the contact points would be burned off very rapidly owing to the frequency of stops in street railway service. To obviate this the contacts are so placed that the point where the circuit is broken lies in a strong magnetic field produced by a coil of heavy wire, called the blow-out coil, through which the entire current circulates. No arc can exist in a magnetic field, as the magnetism immediately ruptures it, and the strength of this rupturing effect depends on the strength of the field, other things being equal. The blow-out coil carrying the entire current, evidently when a heavy current is to be broken the magnetism will be greater than with a lighter current, thus rupturing a heavy arc just as effectually as a small arc. The foregoing is the General Electric controller; that of the Westinghouse Company is similar except that it does not shunt the fields.

As already stated, motor-starters are not motor-controllers, hence should not be used as such. The resistance is usually placed in an iron case, perforated to give good ventilation and heat radiation, and the contact points and the movable arm are mounted on a slate or marble face-plate attached to the case. Figure 76 gives a view of the face of an ordinary starting box, the resistance coils being shown diagramatically. Three terminals are shown. The

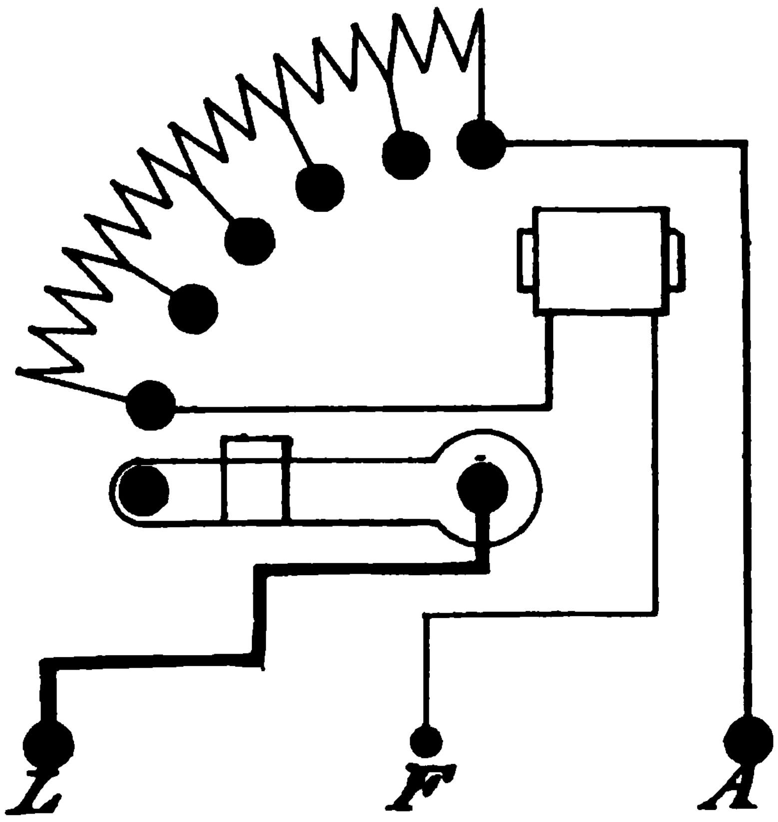


FIG. 76.

connections are always under the face-plate, and as that prevents one from seeing what the binding posts connect with, the manufacturers usually mark them, L for line, F. for field, and A for armature, thus indicating the method of connecting. Should there be no marks, proceed as follows: Place the movable arm in the off position, then take a magnet or ordinary doorbell battery and connect it first across the center post and one of the outside posts; if the bell rings those two posts are the ones that connect to the armature and the field. If no ring is obtained try the center and the other outside post; if no ring is obtained there, try the two outer ones, and if you still get no ring look for a broken connection.

CHAPTER XI.

MEASURING INSTRUMENTS.

The instruments in use for practical electrical measurements are the armature, the voltmeter, and the wattmeter.

Voltmeters and ammeters differ very little in construction; their only difference, practically, is that the former is used to indicate the value of the e. m. f. or difference of potential between two points, and the function of the latter is to measure the intensity of the current in any circuit or conductor. There are two

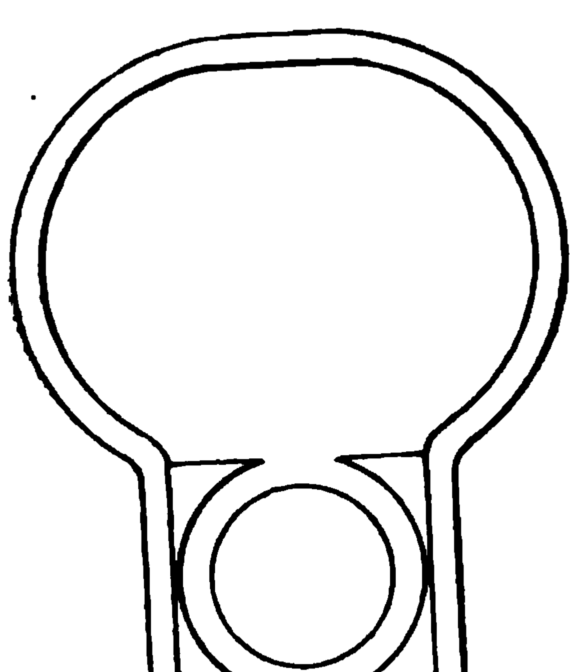


FIG. 77.

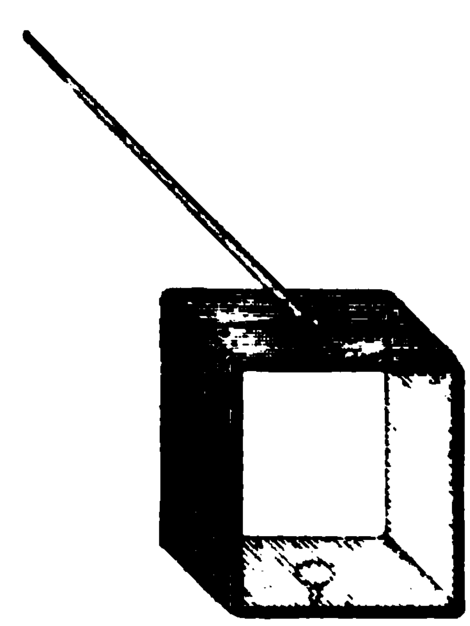


FIG. 78.

types: the L'Arsonval and the Dynamometer type. In the D'Arsonval type of instrument a cylindrical soft iron core is mounted between the poles of a permanent magnet, see Figure 77, the poles of the latter being so shaped as to encircle the greater portion of the core. The air-space between the pole faces and the core, are made of uniform width and large enough to permit a small and light metal bobbin, see Figure 78, to move freely therein. On this bobbin is wound a coil of fine insulated wire,

the ends being brought out and connected to two binding posts, for connection to the circuit the voltage or current of which is to be measured. At each end the bobbin carries a steel pivot which rests in jeweled bearings. These permit the coil to turn freely and with very little friction, thus responding to very small variations in current. As soon as a current flows in the coil the latter tends to move, with a force corresponding to the value of the current; this moving tendency is opposed by the torsion of a small spring or springs which are attached to the bobbin. These springs also serve to lead the current into and out of the coil. Evidently the greater the current flowing, the stronger the turning effort of the coil and the more the latter will be able to overcome the pull of the spring. A light pointer mounted on the bobbin and moving over a graduated and numbered scale indicates the value of the force, either in volts or amperes, according to which is being measured. The suspension of the moving parts being very delicate the pointer would continue to swing for a considerable time when current is started, or would swing backward and forward continuously if the current were a variable one, hence the true current value could never be quickly found. To obviate this swinging of the needle some damping device is necessary, which, while not impairing the sensitiveness of the instrument, will cause it to move more slowly. Instruments having bobbins of metal need no auxiliary damping device to make them "dead-beat," that is, cause the needle to indicate the true current value instantly; since the bobbin moves in a magnetic field an e. m. f. will be generated in it at every movement, which causes a current to circulate in the bobbin in an opposite direction to the current in the coil. This current in the bobbin acts as a drag upon the latter, checking a too rapid movement. Some instruments have a small vane attached to the moving member, the air-resistance of which serves to dampen the movement. In others the entire moving system is immersed in oil, the density of the latter serving to make them dead-beat. Of course the very nature of this type of construction precludes their use as portable instruments, as in moving them about the oil would be sure to get where it is not wanted, that is, over the scale. They are well adapted to switch-board service, however. The immersion in oil effectually preventing dust, dirt and moisture from getting into the vital parts.

Dynamometer type of instruments contain no permanent magnets. There are two coils, one fixed and the other movable, mounted one within the other and the plane of one is at right angles to the plane of the other when no current is flowing; the movable coil being held in this, the zero position, by the torsion of a spring. It is suspended by a thread or a fiber. The ends of the moving coil dip into cups of mercury for connection with the circuit. The current is sent through the two coils in series and the

effect is to rotate the movable coil about its axis so as to bring its plane parallel to that of the fixed coil, the strength of the turning force depending upon the strength of the current flowing. As this type of instrument contains no magnetic material it can be used for alternating as well as direct currents. Another type of instrument used generally for measuring high potential, either a. c. or d. c., is the electrostatic voltmeter, see Figure 79. The pointer is attached to a thin aluminum plate, which latter is suspended in a vertical position on delicate knife edges. On each side of the plate are two metal sheets connected together and also to one side of the circuit to be measured, the other side being connected to the movable plate. A difference of potential between the fixed and movable plates will cause the latter to be deflected from its vertical position.

Kelvin's composite electrical balance, Figure 80, can be used as either voltmeter, ammeter or wattmeter for either a. c. or d. c. current, no iron or other magnetic substance being used in its construction. A beam carrying a coil of wire at each end is piv-

FIG. 79.

FIG. 80.

oted in the center, the two coils coming each between two similar coils arranged far enough apart to allow the beam to be tilted. The tilting effort will depend on the strength of the current. By means of a weight slid along the scale beam this force can be accurately measured, the weight being adjusted to hold the beam in a horizontal position.

Instruments to measure the voltage or difference of potential of any circuit have an auxiliary resistance connected in series with them which prevents an excess of current due to the voltage of the circuit and the low resistance of the instrument. The instrument is connected directly to the two sides of the circuit or the

two points of the circuit between which the difference of potential is to be measured. As the current through the coil will depend directly upon the voltage and the turning effort depends on the strength of the current flow it follows that the pointer will indicate the value of the e. m. f. existing between the two points to which the instrument is connected.

Although such an arrangement will measure the voltage of a circuit, to measure the current strength a different arrangement is necessary, since even when the voltage of a machine or circuit is at its full value there may nevertheless be very little or even no current flowing. Therefore, to indicate the intensity of current the coil should be connected in series with the conductor the current in which is to be measured, so that the value of the latter may effect the motion of the coil. That arrangement, however, would necessitate the use of a coil having conductors of sufficientlly large cross-section to carry heavy currents. Formerly ammeters were so made, and are sometimes even yet in the smaller sizes, but since they are necessarily heavy, and, generally, inaccurate besides being inconvenient and expensive to install, a different method was adopted, viz: Using the same instrument as for the voltmeter, but leaving off the auxiliary resistance. A short strip of some resistance metal, called an ammeter shunt, is connected in series with the conductor the current in which is to be measured. As the resistance of this shunt is a constant quantity, evidently the voltage at its terminals will be directly proportional to the current flowing through the shunt, since according to Ohm's law, the voltage equals the current multiplied by the resistance. The ammeter is connected to the terminals of the shunt, and, when no current flows through the shunt, no difference of potential will exist between these terminals, and the pointer will remain at the zero position. As soon, however, as current flows through the shunt a difference of potential is set up between its terminals, exactly proportional to the intensity of the current, and this difference of potential causes a current to flow through the meter causing a movement of the pointer. The meter, therefore, does not measure the current, strictly speaking, but merely measures the e. m. f. betwen the shunt terminals. As this value is directly proportional to the current, however, the scale can be graduated and numbered to read directly in amperes. As the current through these meters is very slight only a small wire is necessary to connect them to the shunt. They are usually supplied with flexible leads of considerable length to permit placing the meter at the most convenient place without the disadvantage of having to run the heavy circuit conductor there also. In case the leads are longer than necessary they should never be cut off. Altering the length of the leads affects the accuracy of the instrument. The leads that are furnished are

the ones used when it was tested and calibrated, therefore, it will readily be seen that altering their length will increase or decrease the resistance of the meter circuit, of which they form a part, thus altering the ratio of the resistance of the shunt to the resistance of the meter, hence, also, altering the current through the meter with a given difference of potential at the shunt terminals, thus destroying the meter's accuracy. Shortening the leads reduces the resistance of the meter circuit, allowing more than the proper current to flow, which causes the meter to read higher than it should; lengthening the leads, of course, has just the opposite effect. With a. c. ammeters shunts are not used, series transformers being used instead, which will be explained farther on. Their function is the same as that of the shunt, however, viz: To create a slight difference of potential between two points of the conductor whose current is to be measured, thus causing a proportionate current to flow through the meter.

Wattmeters are of two kinds: Recording and Indicating Wattmeters.

The former registers the total energy that has been delivered to a circuit during any period of time; the latter simply indicates the instantaneous value of the energy transmitted at any instant. Since the energy, or the watts, is a product of the volts multiplied by the amperes it follows that a wattmeter must be affected by the values of both these factors at once in order to indicate the value of the product. Therefore, two coils, or sets of coils, are provided; one in series with one leg of the circuit, and the other in multiple with the circuit; the latter is called the voltage or potential coil and is the moving member. Let us consider the indicating wattmeter first.

The voltage coil corresponds to the moving coil of the ordinary volt or ammeter, and its turning force will vary according to the current, with given field strength. The series coil furnishes the field in which the voltage coil moves. Evidently the stronger the current the greater will be the field strength, and hence the stronger will be the force tending to turn the voltage coil. When no current flows in the series coil the pointer will be at zero, although the voltage may be at full value; since there is no magnetic field there can be no force acting on the voltage coil. The current through the latter is very minute and is the same at all loads, on constant potential circuits. Wattmeters are seldom used on constant current circuits, although there are some made for use thereon.

The recording wattmeter differs from the indicating meter in that its voltage coil must be capable of continuous movement in order to record the sum of all the energy values during any

length of time irrespective of such length. Therefore, the voltage coil is mounted on a shaft which can rotate freely, being supported by a jeweled bearing. The shaft supports a light form, on the surface of which a number of coils are wound, making it virtually a drum-wound armature, the end of the coils being connected to a small commutator, with which latter a couple of small brushes make contact. The use of the commutator is to keep the effective plane of the moving coils at right angles to the field. The speed of rotation of the voltage coil is directly proportional to the volts and amperes, that is, the watts of the circuit. A worm on the shaft engages the teeth of a gear wheel connected to a system of gear wheels which register the number of their revolutions on a dial similar to that of a gas meter, the dials reading directly in watt-hours. As the friction of the moving member is slight some damping must be provided to keep the meter from racing. For this purpose a light metal disc is mounted on the shaft and rotated between the poles of permanent

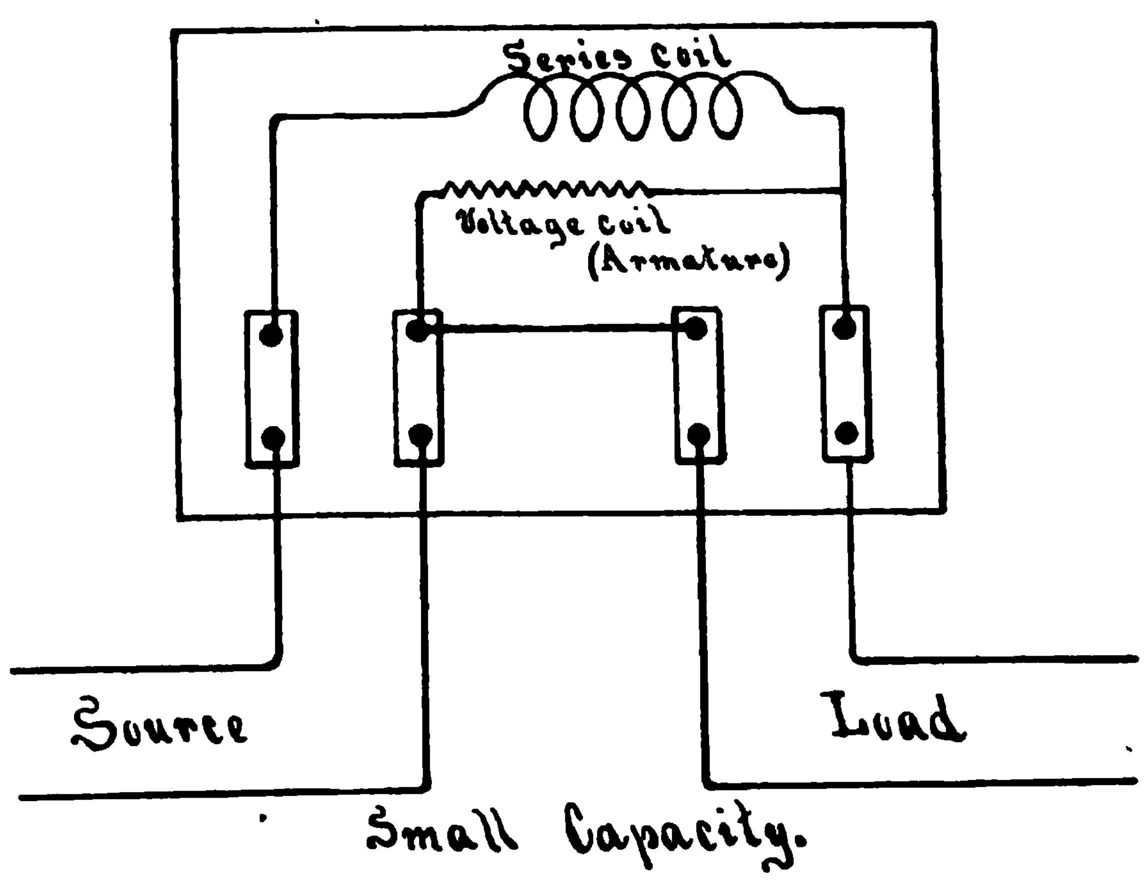
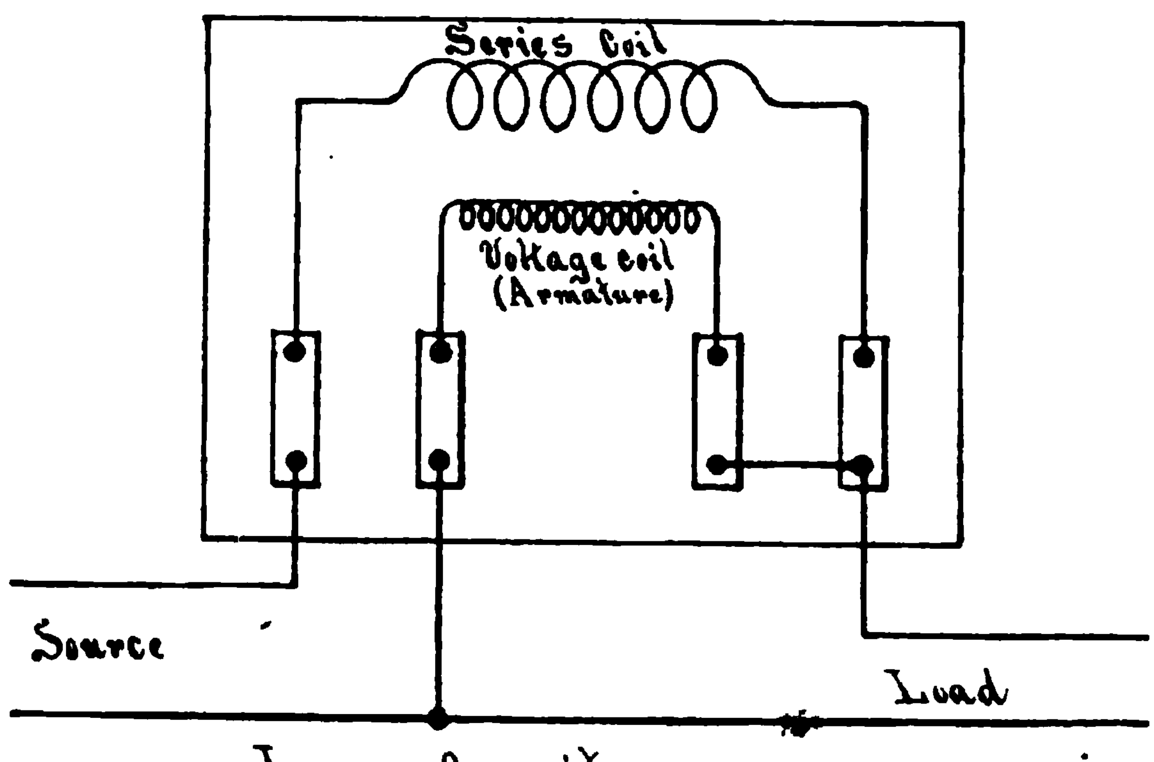


FIG. 81.

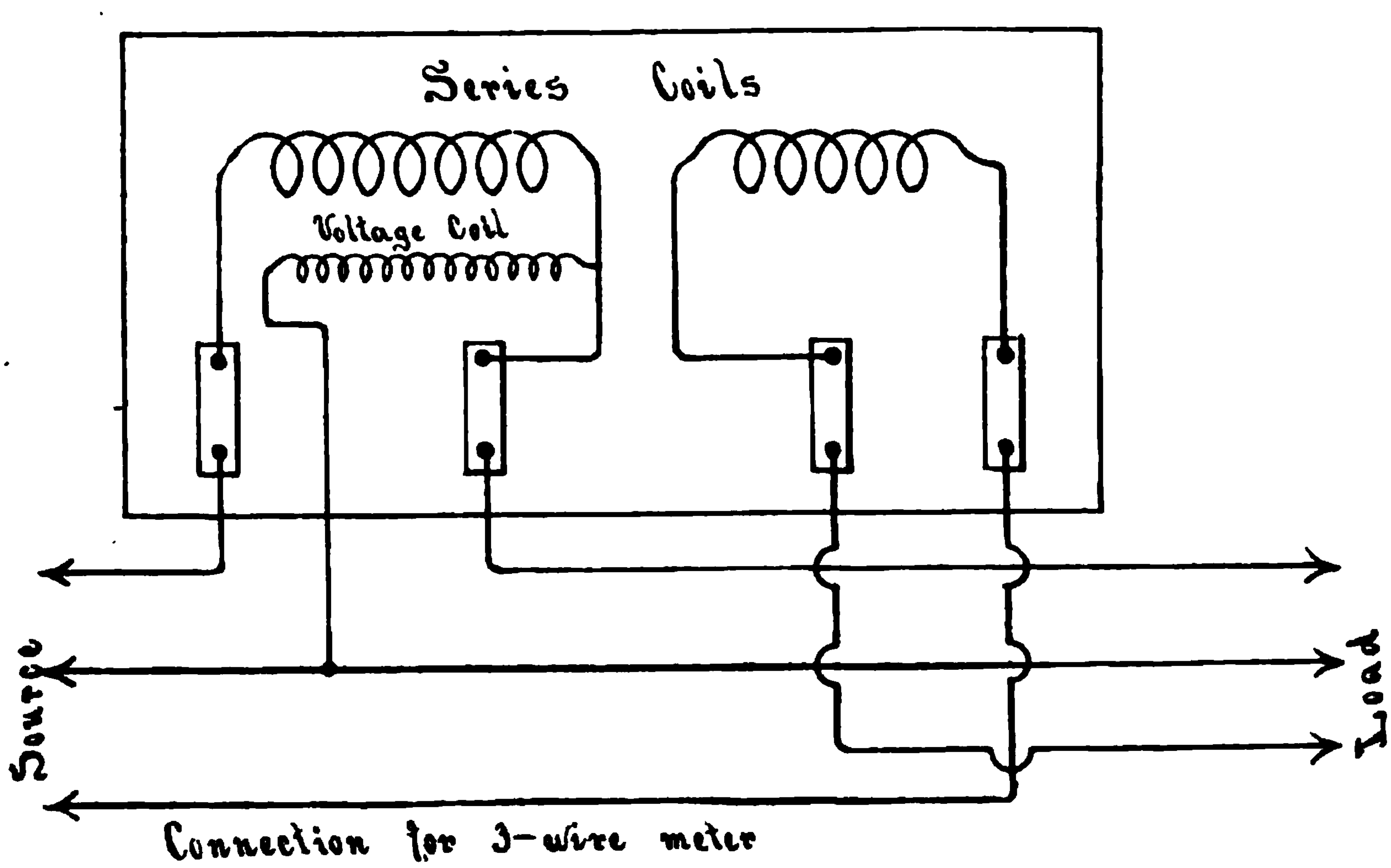
magnets. By its rotation in a magnetic field e. m. f.s are set up which cause current to circulate in the disc, thereby tending to check the rotation of the latter. As the field is constant these currents vary directly as the speed of the disc, hence their damping effect varies in the same proportion. These meters may be used on either a. c. or d. c. circuits, though there is no doubt about the superiority of the induction meter over those of the dynamometer type, just described, for measuring the energy of a. c. circuits. They will be described farther on.

Figures 81-85 are diagrams of various meter connections. Most wattmeters have an auxiliary resistance in series with their voltage coil so that the voltage of the circuit across which this coil is connected can not send a sufficiently strong current through it to cause damage by excessive heating.



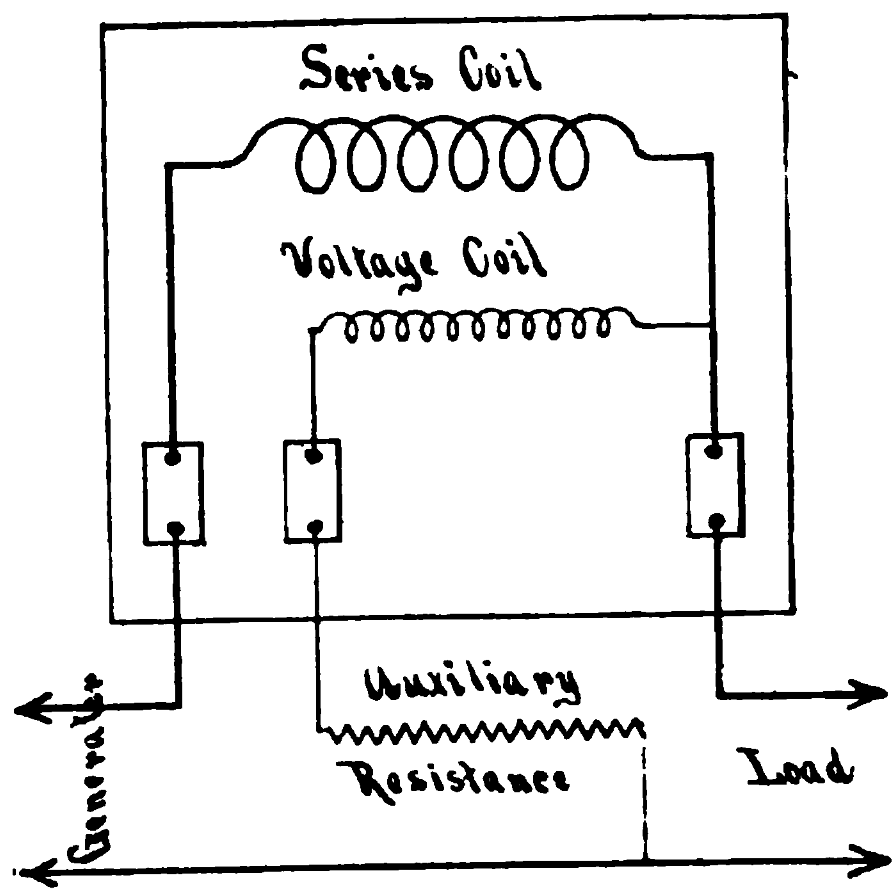
Connections for 2-wire meter

FIG 82.



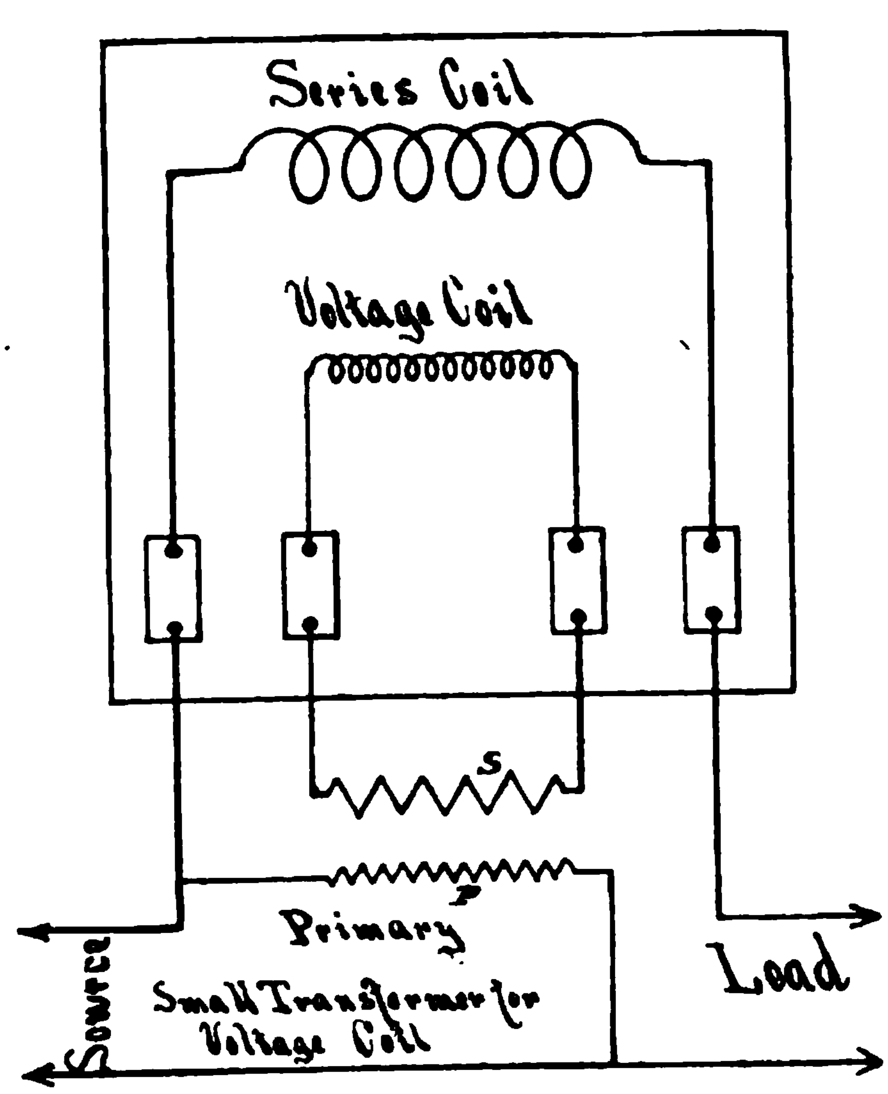
Connection for 3-wire meter

FIG. 83.



Station Arc Meter

FIG. 84.



Connection of Meter on Primary Circuit

FIG. 85.

CHAPTER XII.

PROTECTIVE DEVICES—FUSES, CIRCUIT BREAKERS, LIGHTNING ARRESTERS.

To prevent an excess of current (due to short-circuit or overload) from flowing in any wire, which would heat and possibly melt the latter, fuses or circuit-breakers are employed. The function of these is to open the circuit when the current exceeds a pre-determined amount.

Fuses are strips of lead or other metal or alloy which melts at a comparatively low temperature. In the smaller capacities they are made of round cross-section, the same as wire; in the larger capacities they are made in ribbon form. The area of cross section of a fuse depends principally on the current it is required to carry, though the composition is also a determining factor, some fuse metals having a higher melting point than others and fuses made of such metals are, therefore, made smaller for any given current. Fuses, fuse-wire and fuse-metals are generally marked with their carrying capacity by the manufacturers. Fuses should be mounted on insulating bases which are non-combustible and do not absorb moisture. Fuse blocks, or cut-outs, are generally made of porcelain and are equipped with brass plates, one end of each of the latter serving for the wire connection and the other for the fuse connection; both fuse and wire being firmly held in place by a clamping screw. In the small sizes both circuit and fuse wires may be fastened by bending them around the screw, under the head, and screwing up; in the medium and large sizes, however, both wires and fuses should be equipped with brass or copper terminals, as shown in Figure 86; the connection to be soldered. Fuses thus

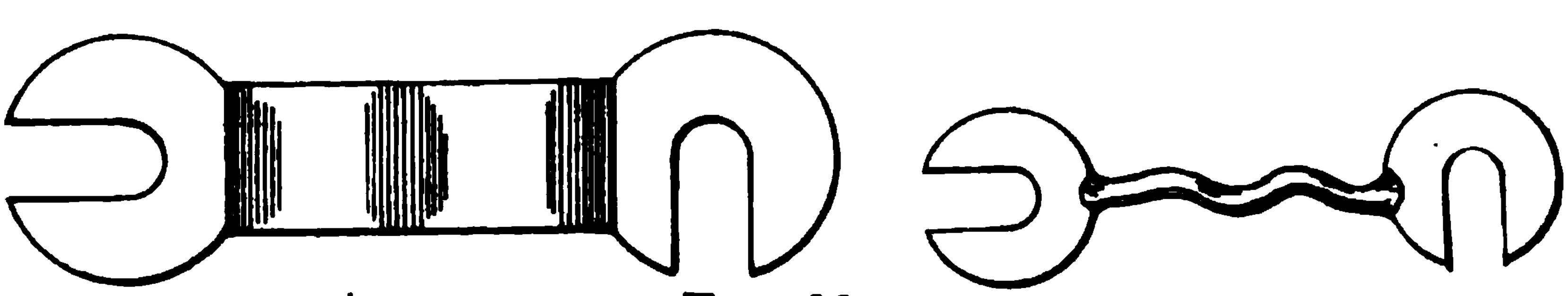


FIG. 86.

equipped are called fuse links, and their capacity in amperes and the voltage of the circuit for which they are intended are stamped on the terminals. They should never be used on a circuit having a higher voltage than they are designed for. The length of a fuse, that is, the breaking distance between its binding posts, is dependent on the voltage of the circuit on which the fuse is to be used. The higher the voltage the longer the breaking distance. The reason for the longer breaking distance at the

higher voltages is that a higher voltage will maintain an arc across a longer gap than a lower pressure, the arc having once been established. Fuses, especially large ones, require a considerable time to heat up to the melting point and therefore will not blow or melt even at considerable overload if the overload be of short duration. Also, if the terminals and wires leading to them be large and massive, they will carry off a considerable portion of the heat generated in the fuse, thus enabling it to stand a given overload for a longer time. The contact between fuse and terminal should be firm and secure, as poor contact causes heating, which might result in melting the fuse when less than the rated current is flowing. Where cut-outs are placed in exposed locations they should have a non-combustible cover, so that the melted metal from a blown fuse can not set fire to the building. They should, preferably, be placed inside a marble or slate-lined iron or an asbestos-lined wooden cabinet equipped with a dust-proof door; in such a case there need be no other cover over the fuses.

The trend of modern practice is towards the use of inclosed fuses; the fuse being in an insulating tube which is filled with a substance that immediately ruptures the arc set up by the melting of a fuse. They are more sensitive than open fuses, though requiring a longer time to heat up with a given current, owing to their being surrounded by material which is, in most cases, a better heat conductor than air, thus carrying the heat off more rapidly. There is an entire absence of flying of molten metal when the fuse blows, which is a great advantage, especially in the larger sizes, where its volume would be considerable. The danger of fire is thereby entirely eliminated.

The circuit breaker is a device for opening the circuit by means of a magnet actuated by the current in the circuit. Two terminals are connected together by a contact bar mounted on a movable support, the latter being impelled by a stiff spring to keep the contact bar away from the terminals, in which position the circuit is open. When the circuit is closed, the spring is under tension, but can not force the contact bar out, because the latter is held by a catch. A coil is connected between one of the line wires and one of the circuit breaker contacts, so that the line current must flow through it. This magnet has an iron core or plunger which can be raised or lowered by set screw. As long as the current is at or below that for which the instrument is set, the magnet can not raise the plunger, but as soon as the current exceeds that amount the plunger is pulled up sharply, and as the arrangement is such that it must strike the catch which holds the contact bar against the tension of the spring the catch is thereby released, permitting the spring to force out

the contact bar, thus opening the circuit very quickly. As the opening of a circuit in which a heavy current is flowing is attended by an arc of considerable magnitude, which would cause the contacts to be badly burned, some means of obviating this difficulty must be employed. Some circuit breakers are arranged that the ultimate break occurs between blocks of carbon, which is not badly affected thereby. Others are arranged so that the break is situated between the poles of an electro-magnet, the magnetism of the latter immediately rupturing the arc and preventing the burning of the contact points. Circuit breakers have been built to break as much as 5000 amperes. They are used on both d. c. and a. c. circuits, and are made both single, double and triple pole. They are used principally on switchboards. When used on motor circuits fuses are, as a rule, also used, as the starting current of motors, especially series motors, is sometimes 50 per cent. greater, or even more, than the normal running current. The action of a circuit breaker being, practically, instantaneous, any overload of no matter how short a duration, would open the circuit. Therefore, they must be set so as to carry the extra current of starting, and as this is needed only a few moments the circuits would have no protection against a steady overload just a trifle below the releasing point of the circuit breaker. Therefore, fuses are used having a lower capacity than the breaker and, as it takes a few moments to heat them to melting point, the momentary overload will have passed before they have time to melt. A continued overload, however, will melt them even if it can not trip the circuit breaker. On an excessive overload or short-circuit the breaker would, of course, come into play, opening the circuit instantly and without any molten metal flying around or dicoloring the switchboard, which occurs where open fuses are on the front of a board. By this means good protection is obtained against both heavy momentary overloads and continued overloads of lesser magnitude. Of course, the circuit breaker can be set to open at any desired current strength, but if set only slightly above the normal current, it would trip every time a heavy pull were required of the motor.

In some circuit breakers, designed for high potential service, the break occurs in a receptacle filled with oil, the arrangement being similar to an oil break-switch. In either case, breaking the circuit in oil prevents the arc which would otherwise occur as a result of the high voltage.

Although it would take a very high voltage to jump across a gap of a small fraction of an inch (approximately 5000 volts for .225 of an inch, between needle points), a very low voltage will maintain a pretty long arc when the arc has once been

established. This is clearly shown in the ordinary arc lamp, where fifty volts will force 9.6 amperes through an arc from three-sixteenths to one-fourth of an inch long, (approximately the same as the sparking distance of 5000 volts), the voltage being only 1 per cent of that required to jump the same distance.

Lightning arresters are placed on all overhead outside lines, being placed as near the point of entrance to or exit from the power station as convenient, and also on the poles along the line at intervals of say one-quarter to one mile, depending on local conditions and the line pressure used. On series arc circuits only two are used, as a rule, one on each leg of the circuit at the station. If on constant potential lines the discharges through the station arresters are frequent it is a good plan to put on some additional arresters along the line, the main object being to divert the lightning charge to the ground and to keep it from entering the apparatus. Lightning is due to a great difference of potential between the earth and the vaporous-strata which we call the clouds, which difference of potential arises to such an enormous value that it breaks down the insulation resistance of the intervening space and a discharge takes place which equalizes, partially, at least, the great difference of pressure. Overhead electric lines have a peculiar affinity for these discharges; if there is a convenient and easy path provided for the passage of this discharge to ground no damage will result. The easy path is provided in the lightning arrester. But that appliance must also serve another function, namely: To interrupt the flow of line current which would follow the path of the lightning discharge. For this reason lightning arresters are so constructed as to permit only a momentary passage of current, a lightning discharge being only momentary. In principle they are shown in the diagram, Figure 87, P P are brass plates connected shown. The length of the air gap between the contacts depends on the voltage of the circuit they are intended for. A lightning discharge has

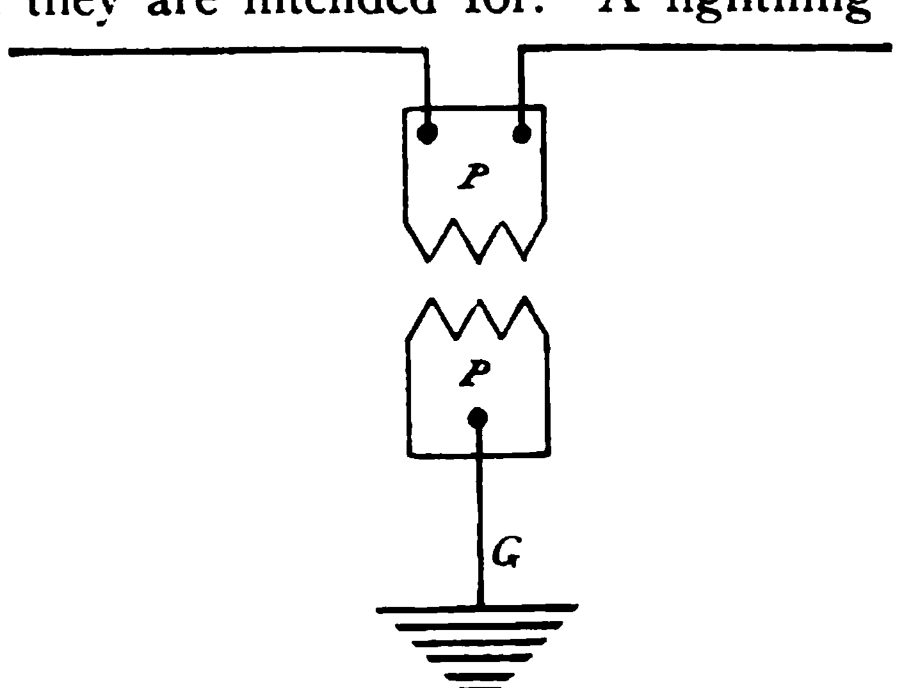


FIG. 87.

sufficient voltage to jump across the gap and the discharge passes to earth. An arc being established between the wire and the ground, the current tends to follow; moreover, the arc fuses the tips of the arrester, thus permanently bridging the gap and grounding the system through the ground wire G. Therefore, the plates of lightning arresters are made of non-arcing metal. As the metal does not arc, the resistance of the gap is not decreased, hence, as soon as the discharge has passed, the flow of current is interrupted because the line voltage can not maintain a flow of current through the high resistance of the air gap.

In the T. H. arrester the plates, P P, are located in a magnetic field, and an arc set up between them will be immediately blown out by the magnetic lines, the latter forcing the arc upwards, thus increasing its length to such an extent that the line voltage can no longer maintain it and the arc must break.

The use of choke coils in connection with station arresters on constant potential circuit is a great help to divert the charge through the arrester. They are connected into the wire between the machine and the point where the arrester tap is made, as shown by the diagram, Figure 88. As a lightning charge has a

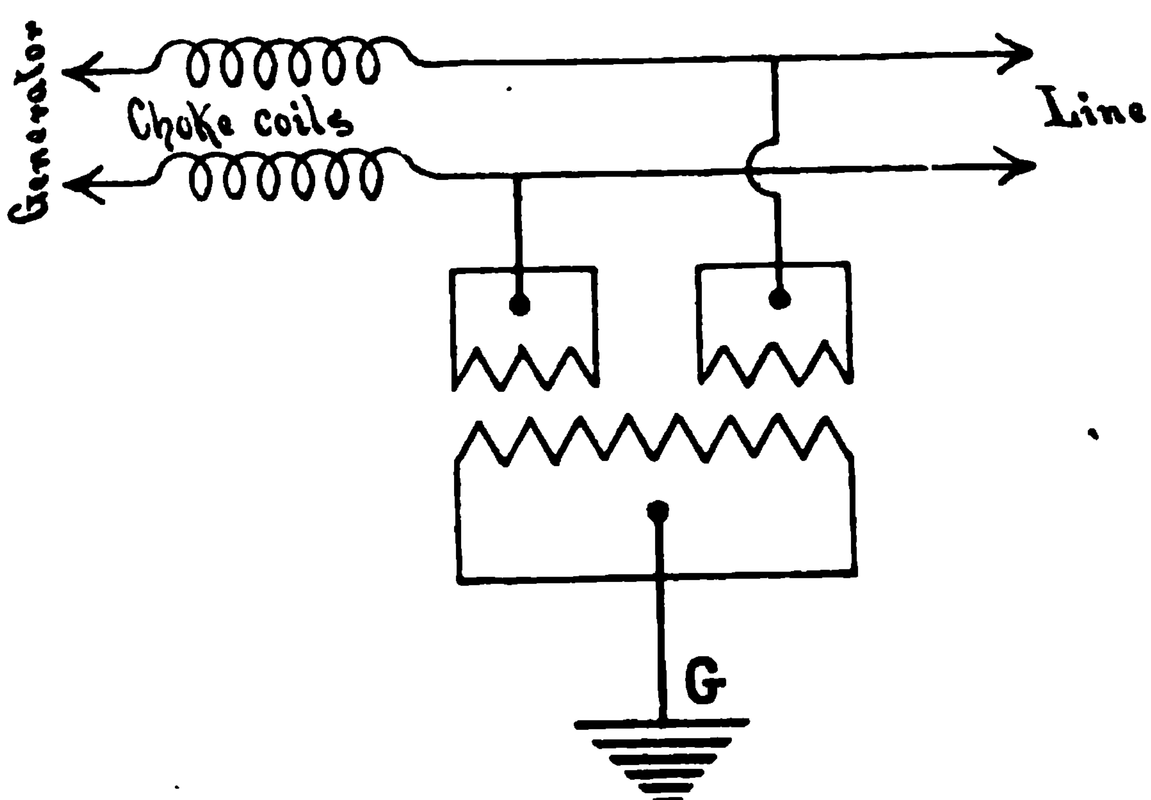


FIG. 88.

great aversion to any inductive path, the insertion of one or more of these coils will generally prevent the passage of a charge through them.

The ground wire from a lightning arrester should be nearly the same size as the line wire, but in no case should it be smaller than No. 6, B. and S. gauge, and all turns should be avoided if possible; if a turn must be made it should be made with a curve of large radius. Never make a square bend nor put the ground wire in an iron pipe, as that introduces reactance. The ground

connection should be made by soldering the ground wire across the entire surface of a metal plate at least 2 feet square, the latter buried where it will be in moist earth even in dryest weather. Pole arresters are secured to the poles and one side connected to the line and the other to the ground, which latter should be made as already described; and all connections should be soldered and the wire connections should also be tapped.

CHAPTER XIII.

SWITCHBOARDS AND GENERATOR CONNECTIONS.

To facilitate connecting or disconnecting generators to or from the distributing system, or to permit cutting in or out portions of the latter, switchboards are provided. They are built of slate or marble panels, the different switches, measuring instruments, regulating devices, etc., being mounted thereon. The panels are supported by and attached to angle or T irons fastened to the floor at one end and to the wall at the other by suitable braces, there being enough space left between the board and the wall to readily permit a man to go behind the board to replace blown fuses, etc. All the wiring is on the back of the board, as is also the generator field rheostat, the shaft of the latter going through the panel and having a hand wheel on the end on the front of the board. The heavy wires, rods or bars that connect the different switches to the generator switch are called bus-bars, and are usually made of copper, though aluminum is sometimes used. Their cross-section is usually such that the current density at full load shall not exceed 1000 amperes per square inch of bus-bar area. Switch blades are generally designed to have a cross section of one square inch per 800 amperes and the area of contact between the blades and the clips or jaws is about 1 square inch on each side per 100 amperes; the large area being taken to prevent waste of energy due to heating of switches and bus-bars which would occur if the current density were much higher. The above figures are for copper; for aluminum the current density is usually only about 60 per cent. of the above. It should be noticed that the switches in the diagrams all hinge at the bottom and are so connected to the source that when the switch is open the blades shall not be alive. The reason for placing switches hinge downward is that thereby an accidental closing due to the force of gravity is prevented. The hinge post of a switch may be used as a current post also, but in that case spring washers should be used under nuts on the hinge pin. Such switches are called single break switches, while those in which the hinge post does not carry any current are called double break switches. Figure 89 shows a single

break switch on the left and a double break on the right, both being double pole, that is, capable of opening or closing both legs of a circuit. Figure 90 shows a triple pole switch. The cross bar, B, at the top is usually made of fiber, which is mechanically strong and also a good insulator, and the handle of wood. The blades and clips are made of hard drawn copper, though the latter are sometimes made of phosphor-bronze, the latter material being springier than copper, although its conductivity is less. Sometimes it is desired to have a switch that will connect one pair of bus-bars to either one of two generators or one generator to either one of two circuits, in which case a double throw switch is used. Such a switch is equipped with additional clips as shown in Figure 91. The distance between clips of opposite polarity, and the breaking distance of a switch depend upon the voltage for which the switch was designed, and is regulated by the rules and requirements of the National Board of Fire Underwriters, a copy of which can be obtained at any fire insurance

FIG. 89.

office. The studs upon which the clips are fastened project through the board and have a long thread which permits a nut to be run up against the board, thus firmly clamping the stud in place. Bus-bars are secured thereto by clamping them between two nuts on the stud, a hole a trifle larger than the latter having been previously drilled in the bar. When such switches or switchboards are installed, the former should be tested to see if they are lined up, that is, if the clips are in line, as if this is not the case the amount of contact surface between clips and blade will be greatly reduced, causing the current to heat the switch at the poor contact. The test can be made with a piece of very thin mica, by endeavoring to insert the same between the clip and blade, which can not be done when the switch is all

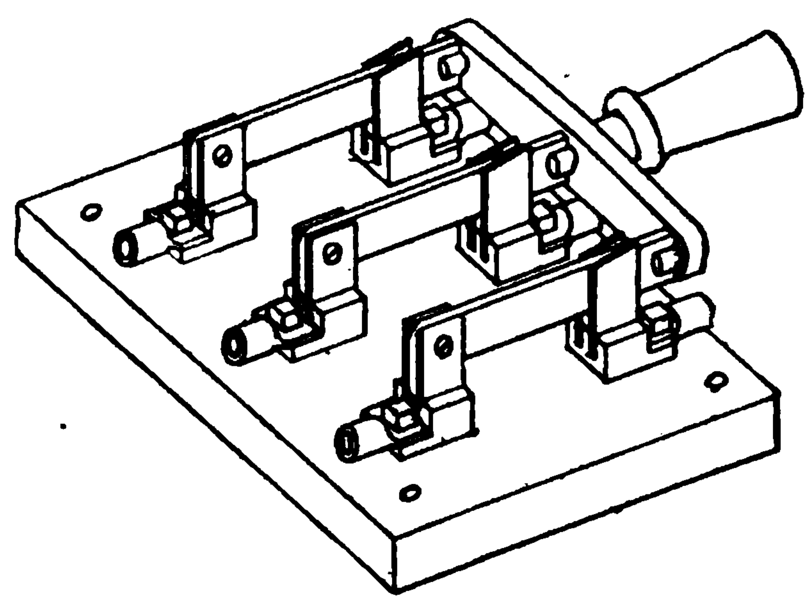


FIG. 90.

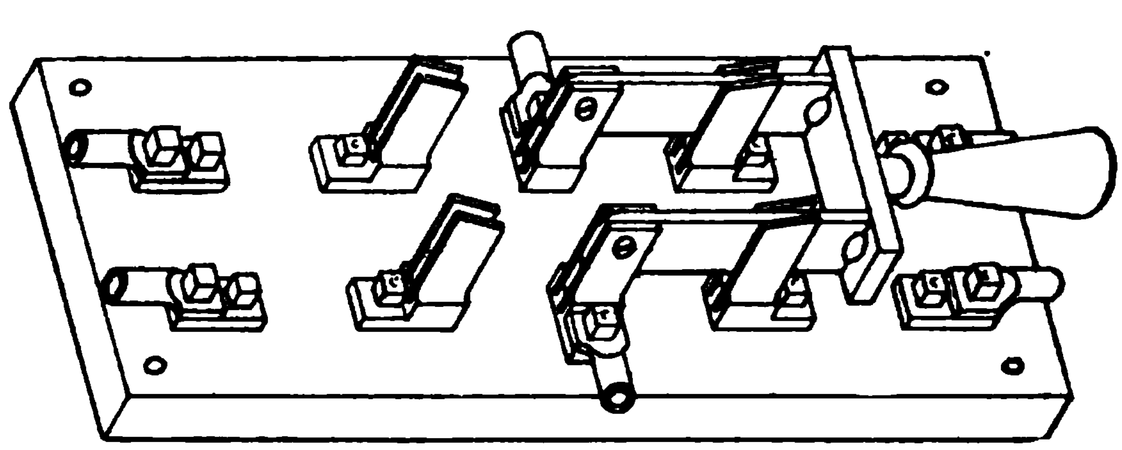


FIG. 91.

right. The direction in which a clip is out is indicated by the location of the openings into which the mica can be inserted. This lining up requires considerable skill and should not be attempted by any one who is not a good mechanic, as a switch is very easily ruined.

Measuring instruments are usually placed on the face and near the top of a board; some of them are made so that only the dial shows on the face, a hole being cut in the board to permit the other portion to project behind the board. They differ from portable instruments in form only, having a different

case and large open scales capable of being read at a distance. As a rule they are not as accurate as the portable instruments.

Recording wattmeters are usually mounted on the sub-base of the board, which is a small panel placed between the main panel and the floor.

Figure 92 shows a single panel switchboard for connecting one generator to three feeder circuits. M S is the generator switch, F S the feeder switches, R the hand wheel of the field

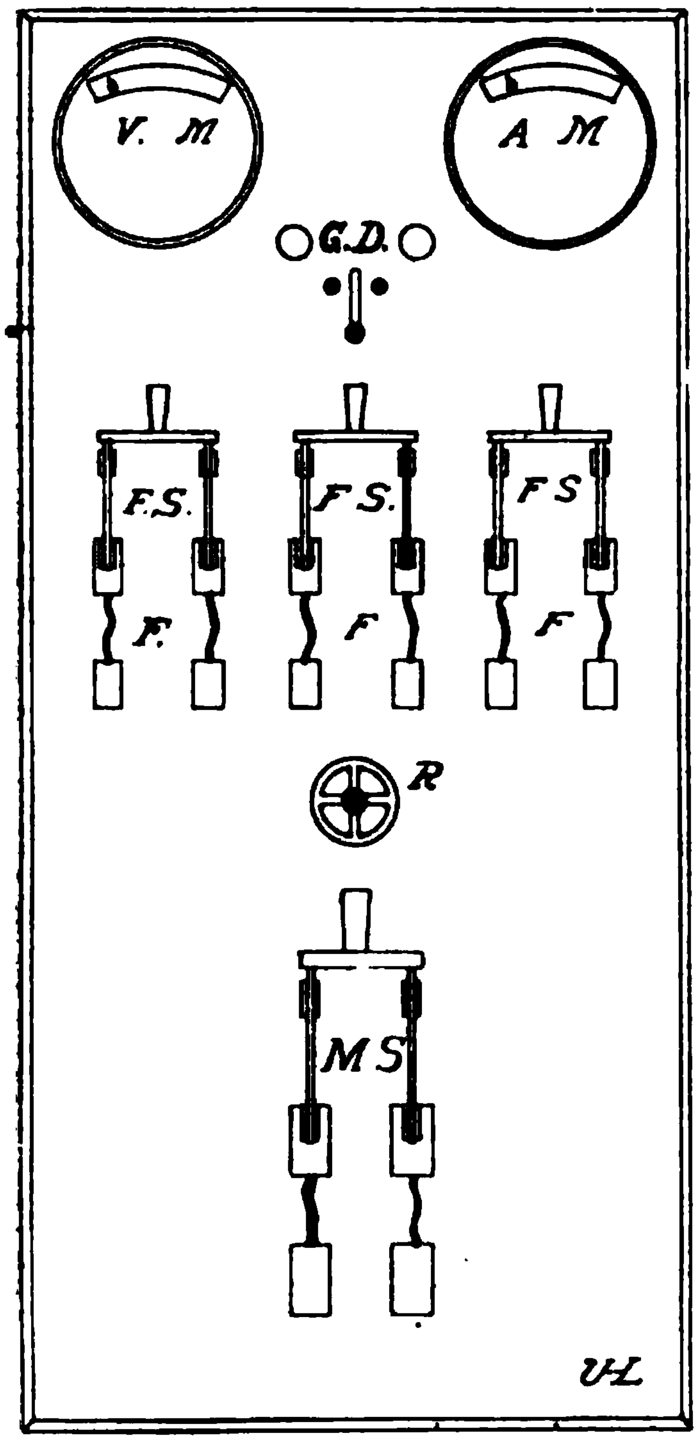


FIG. 92.

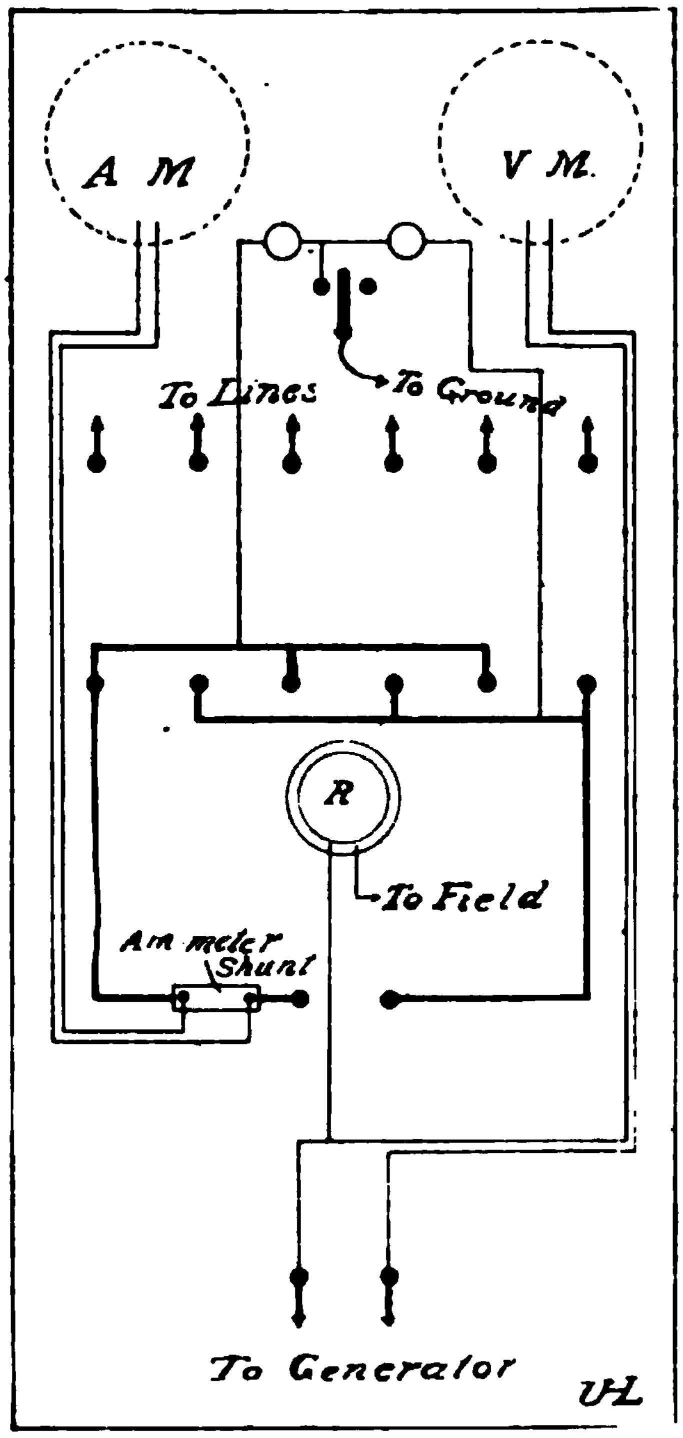


FIG. 93.

rheostat, F the fuses, A-M the ammeter, V-M the voltmeter and G-D the ground detector switch. The connections are shown in Figure 93.

Figure 94 shows a two-panel board for connecting two compound-wound generators to feed into the same feeder system together. It will be noticed that the generator switches M S are triple-pole. The middle pole is used to close the equalizer connection. The reason for the equalizer is that, as the machines are compound wound, when the speed of one of them falls below

that of the other its e. m. f. would fall correspondingly, therefore, current would flow through the equalizer from the stronger to the weaker machine, part going through the field and part through the armature of the latter, driving it momentarily as a motor, thus enabling its speed to rise. The connections are shown in Figure 95: E being the equalizer, which, it will be noticed, is connected to each of the machines between the armature and the series winding. It should be remembered that in the case of compound machines in parallel the ammeter should always be connected in the opposite side of the circuit to which the series field is connected, as shown in Figure 95. Sometimes the equalizer switch, instead of being mounted on the switchboard, is placed on a pedestal near the machine, to avoid the long run of a heavy equalizer wire between the latter and the switchboard, it being only necessary to run the wire from one machine to the other, in this case. The equalizer is not needed where shunt machines are used. The field of a compound machine may be connected as shown in Figure 96, which is the short shunt, or as

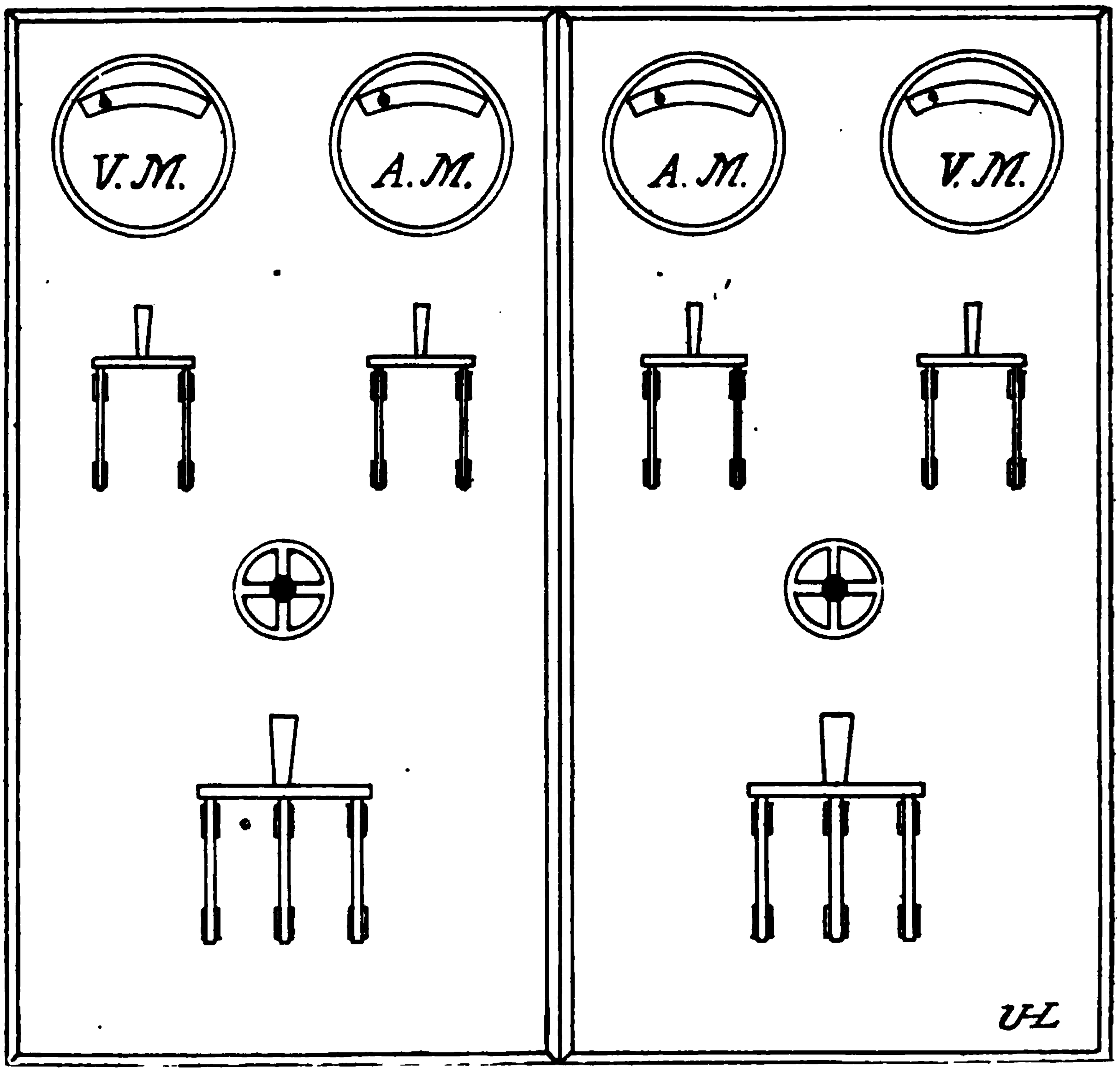


FIG. 94.

in Figure 97, which is the long shunt. In the latter, the drop in the series winding increases the e. m. f. applied to the shunt winding as the load increases, thus increasing the current and hence the magnetizing force; the difference is small, however.

Figure 98 shows the connection of two generators for a three-wire system, the two machines being connected in series, that is, the positive terminal of one is connected to the negative of the other. A tap is then taken from any point in this connecting wire and brought to the middle pole of the triple pole switch at the switchboard. This is called the neutral wire.

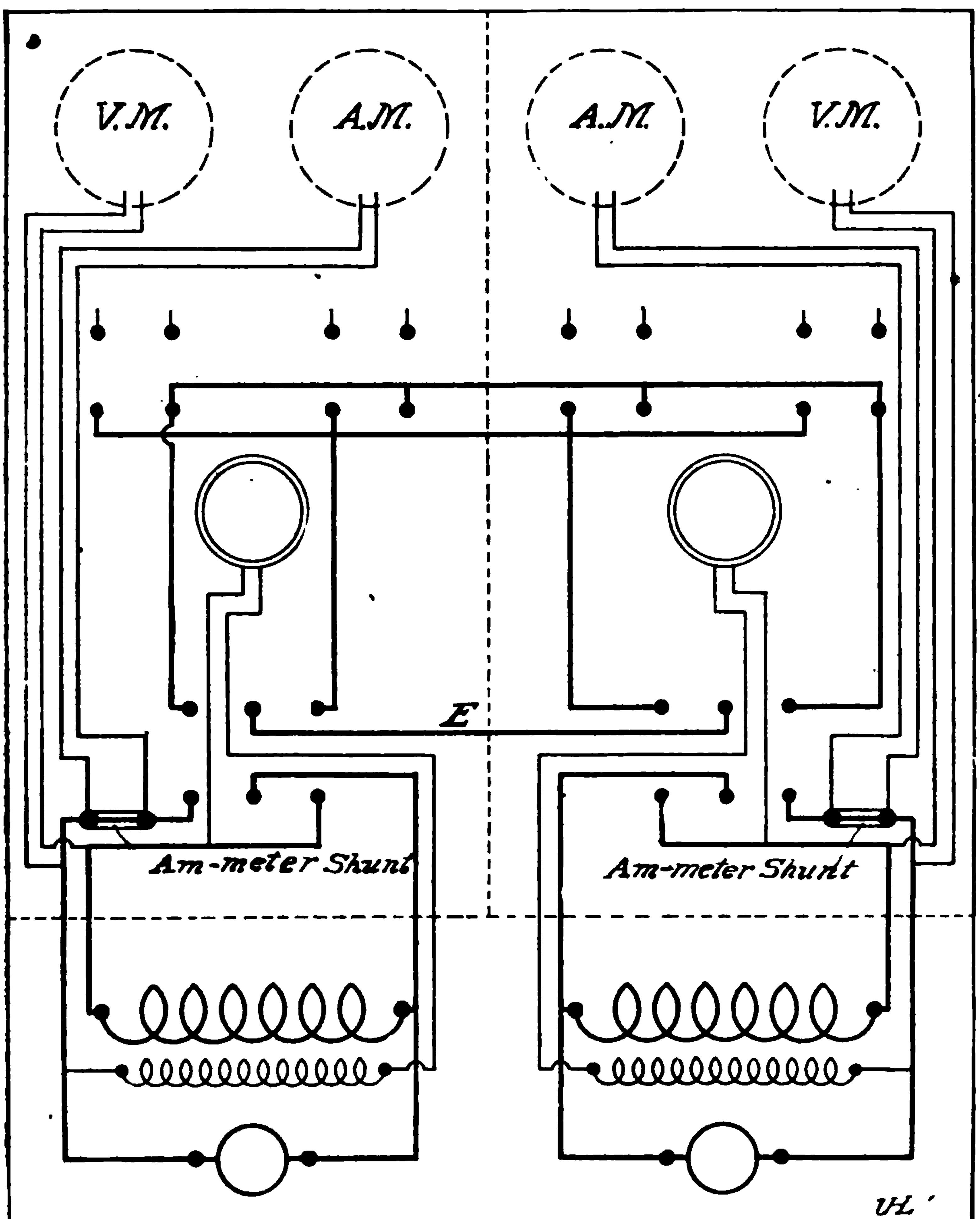


FIG. 95.

The function of the ground detector is to show when a ground occurs on either leg of the system. Two lamps in series are connected across the two sides of the circuit and a tap is taken from between the two lamps and connected to the ground. As long as the circuit is clear the lamps will burn dim; as soon as a ground occurs on one side of the circuit the lamp connected to that side of the circuit will go out and the other will burn bright, as one side being in direct connection with the ground the full generator voltage will exist between the latter and the clear side of the circuit. Instead of the lamp arrangement a

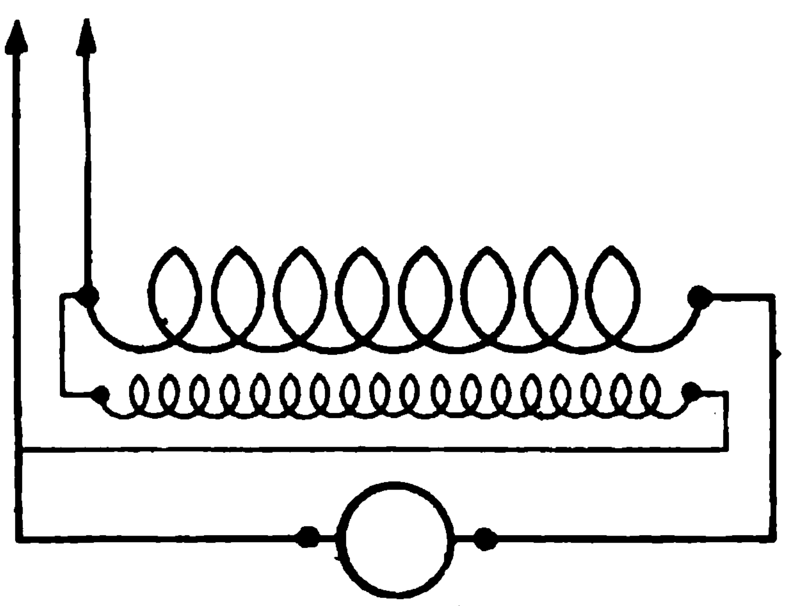


FIG. 96.

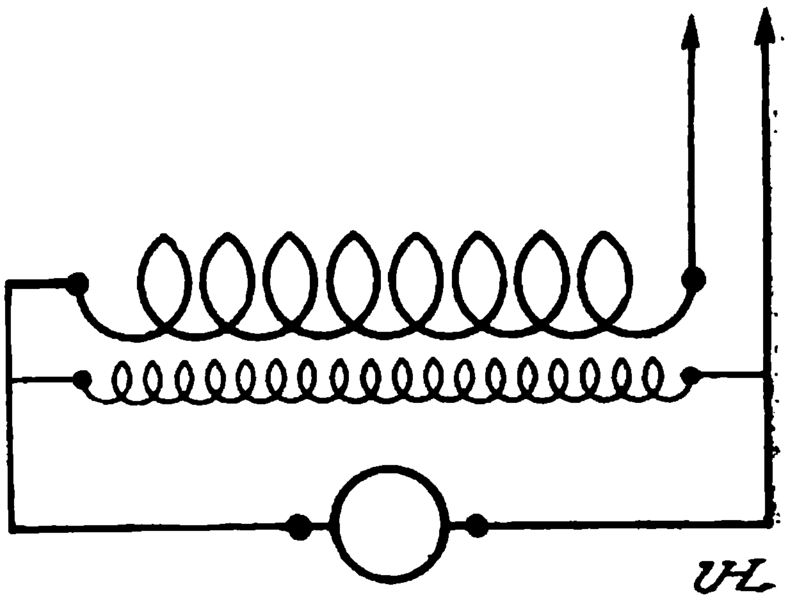


FIG. 97.

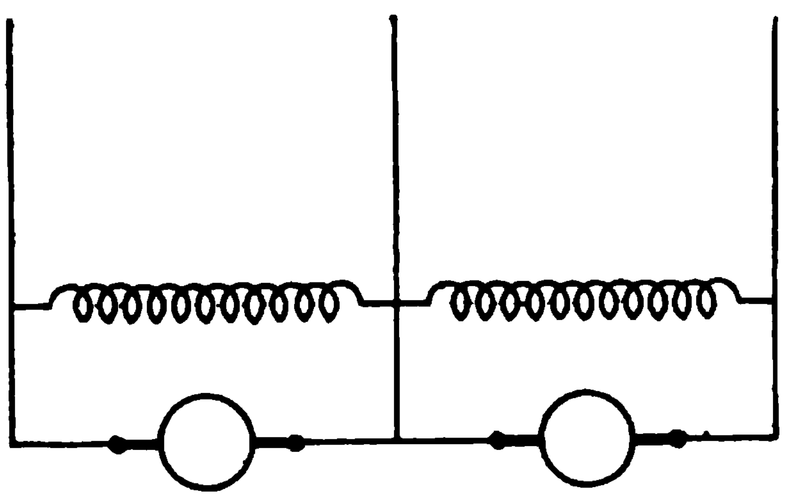


FIG. 98.

voltmeter can be used, if a voltmeter switch is provided. Figure 99 shows such a switch of 5 points to test two circuits and also indicate the voltage of a generator. The voltmeter is connected to the two semi-circular strips and the various line and machine connections are as shown, the four lower contacts on the right-hand side connecting to ground. The arm A is pivoted at the center and carries a contact shoe at each end. These contact shoes are insulated from the arm and make contact between the voltmeter terminals and one of the outer terminals on each side, the distance between the latter being such as to prevent the shoes from touching two adjacent segments at once. By a manipulation of this switch evidently the voltage of the machine, or

that between the ground and either leg of either circuit can readily be found. If there is a ground on any wire the voltmeter will show full machine voltage between the ground and the opposite leg of the grounded circuit. When there is no deflection the opposite leg to the one the voltmeter is connected to is clear. Voltmeter switches can be made with any desired number of points, however, care must be taken to have the segments far enough apart that the contact shoes do not touch two segments at once when being moved from one point to another.

Switchboards for arc machines are built somewhat differently. Most arc boards now built are what are known as plug boards. Two panels, one behind the other, are mounted on suitable supports, leaving an air-space of 8 or 10 inches between them. Each of them is pierced with holes spaced equidistant apart, each hole in the front panel being in line with one of the holes in the rear panel. Circular metallic clips are mounted on the back of each panel so that a plug inserted in a hole would pass through and make contact with both a front and rear clip. The plugs are made of sufficient length to reach through both panels and are equipped with a handle at one end. Thereby the front

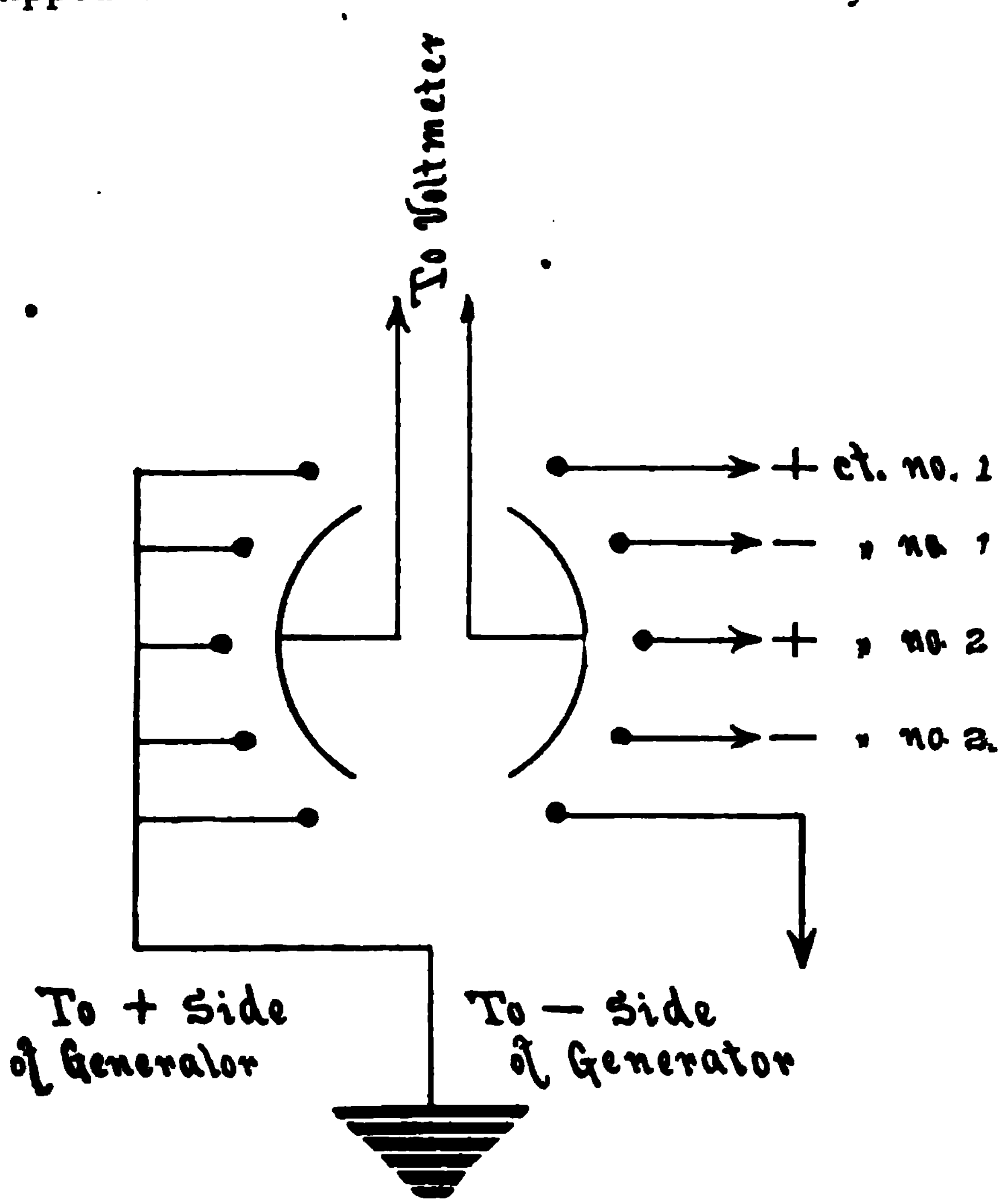


FIG. 99.

and back clips are connected together. The circuits are each connected to one row of holes in the front panel, say a horizontal row; the machines are each connected to a vertical row of holes. By means of this crossing any machine can be connected to any circuit, there being as many rows of holes and as many holes in each row, as there are circuits. These boards, moreover, are divided into two sections, positive and negative, all positive machine leads going to the rear panel of the positive section of the board, and the negative machine leads going to the rear panel of the negative section. The positive and negative line wires go to the front panels of the positive and negative sections respectively. The reason for connecting the lines to the front panels is to enable the station attendant to test them without going back of the board, also to make the plug dead when not all the way in, whether the machines are running or not; and further to permit connecting two circuits together from the front. As a little con-

FIG. 100.

sideration will show, neither of these things would be possible if the machines were connected to the front panel. Should it be desired to connect two circuits together it can be done by two short plugs connected together by a piece of flexible wire; one plug is inserted in any hole of the positive section of one of the circuits to be connected, and the other plug is inserted in any hole of the negative section of the other circuit. The remaining line terminals are then plugged to the machine it is desired to use, just as if it were one circuit. Figure 100 shows a three-circuit board, positive on the right and negative on the left; the smaller circles are the machine terminals at the back and the larger holes are the circuit terminals. It is desired to run No. 1 and No. 3 circuit together, cutting off No. 2 machine. We push in a long

plug in the first or left hand hole of the middle or No. 2 horizontal row of the positive section; that connects the positive side of No. 1 circuit with the positive side of No. 2 machine. Then insert a long plug in hole No. 1 of the No. 2 horizontal row of the negative section, which connects the negative side of No. 2 machine to the negative side of circuit No. 3; we now take our flexible wire with the short plugs, and insert one in any hole of the second horizontal row of the positive section, and the other plug in any hole of the bottom row of the negative section, which completes the circuit. The circles in which the plugs are inserted are shown dark and the connection between the front and rear circles are indicated by dotted lines. To connect, say circuit No. 1 to machine No. 2, insert plug in second hole of top or No. 1 horizontal row of the positive section, and another in the same relative hole in the negative section.

Two constant current machines may also be connected in series, provided their current capacities are equal, to run a circuit which is too heavy for one machine alone. The positive terminal of one machine is connected to the negative of the other, the

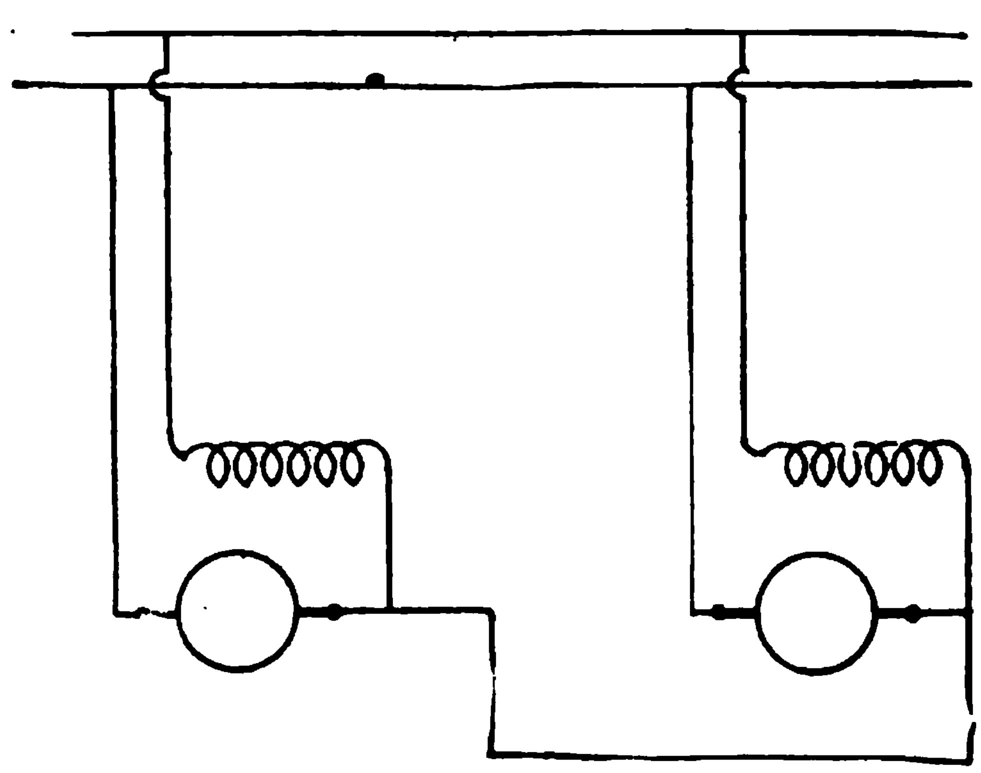


FIG. 101.

circuit to the remaining two. If the machines are equipped with automatic regulators one of them should be cut out, or rendered inoperative by fastening the lever in one position, and letting the other one perform the regulation. Since two regulators seldom work well together, one of them working either too fast or too slow, they would run back and forth continually in their effort to establish equilibrium. However, the load variation should not exceed the capacity of one machine, and the sum of their capacities must be at least equal to the requirements of the circuit.

There is, moreover, nothing to prevent series machines from being connected in parallel if precautions are taken against a

reversal of one machine in case its speed should fall below that of the other. As a reduction in speed would also cause a reduction in current, which would weaken the field, thus further reducing the current and, hence, still more weakening the field. The ultimate result would be a reversal of the machine; this can be avoided by the equalizer wire, as shown in Figure 101. or by connecting them so that each will excite the other's field.

CHAPTER XIV.

INCANDESCENT LAMPS.

The incandescent lamp is a very simple device, much simpler than the arc lamp, being only a thin strip or filament of carbonized vegetable matter. Yet, greater care is necessary in its manufacture than is required for arc lamps. The filament of an incandescent lamp must be of uniform cross-section, must be capable of enduring a very high temperature for a great length of time, must not be easily broken, must not blacken the inside of the globe, must possess a high efficiency, that is, must give as much light as possible for a given current consumption, and the amount of light it emits must not decrease, nor must the current it consumes increase, to a great extent, as its length of service increases. Thus, it is seen that the demands made upon it are numerous and exacting.

To obtain a bright light a material must be employed which does not readily fuse, and in order to keep it from burning the air must be excluded from it. Carbon is used for this purpose, a fine thread, called a filament, being hermetically sealed into a glass globe from which the air has been exhausted. To carry the current from the filament through the glass to the terminals of the lamp, a short piece of platinum wire is secured to the ends of the filament, the glass being fused around them. The platinum is secured to the filament by an electrolytic deposit of copper. At their free end the platinum wires are connected each to a copper wire which is attached to one of the lamp terminals, which latter, together with the insulating support that separates one from the other and also holds them securely to the globe, constitute the base. The reason for the use of platinum is be-

cause the expansion and contraction, due to heating and cooling of platinum and glass are practically equal, the platinum also being capable of standing the high temperature necessary to fuse the glass around it. The filament is prepared by taking a fiber of some vegetable matter and heating it to a very high temperature, while at the same time keeping the air from it; the filament is then allowed to cool and is then connected to the leading-in wires, which are previously secured to a glass tube, the end through which the platinum goes being fused together around the latter. The filament is then "flashed," that is, surrounded by a vapor containing a high percentage of carbon and a sufficient current sent through it to bring it to a dull glow. The heated filament decomposes the vapor, the carbon in it being deposited on the filament. If the resistance of the filament is uniform it will have an equal temperature, but if its resistance is higher at some points than at others these points will heat first and receive a deposit of carbon which reduces their resistance. By gradually increasing the current the deposits of carbon will eventually make the resistance uniform throughout the entire length of the filament, hence the brilliancy will also be uniform. The glass tube that carries the filament is now inserted into the globe and is fused thereto, and the lamp is ready to be exhausted, which is done by a mercury air pump, connection between lamp and pump being made by a glass tube secured to the tip of the lamp. When the exhaustion is nearly complete the filament is brought to incandescence by a current of proper strength; this drives off the air which has condensed on the inner surface of the globe or been absorbed by the filament. Failure to do this results in greatly reducing the life of the filament, as the oxygen remaining in the lamp would be liberated the first time the lamp were burned, thus ruining the vacuum and quickly burning out the filament. When the vacuum has reached the proper stage the globe is fused together at the tip, thus effectually sealing it and also disconnecting it from the air pump. As soon as the base is put on the lamp is ready for testing. The test is to determine the voltage necessary to bring the lamp up to the required c. p., and the amount of current consumption.

Incandescent lamps should always be used on a circuit whose voltage is precisely that at which they are rated. If connected to a circuit of lower voltage than the lamp requires, of course no harm results, except that the lamp will not come up to full c. p.; should the lamp be connected to a circuit whose pressure is too high, its c. p. would be increased at a greater rate than the excess of voltage and its life would be shortened in yet a greater proportion than its increase in c. p.; this can be seen by the table on next page, published by a large lamp manufacturing concern.

TABLE—Showing Effect of Various Voltages, Above and Below Rated Voltage, Upon the C. P., Life and Efficiency of Incandescent Lamps.

Per cent of Rated Voltage.	Per cent of Rated C. P.	Life—Hours.	Efficiency.
90	53	....	4.68
91	57	....	4.46
92	61	....	4.26
93	65	....	4.1
94	69.5	....	3.92
95	74	....	3.76
96	79	....	3.6
97	84	....	3.45
98	89	....	3.34
99	94.5	....	3.22
100	100	1000	3.1
101	106	818	2.99
102	112	681	2.9
103	118	562	2.8
104	124.5	452	2.7
105	131.5	374	2.62
106	138.5	310	2.54

From this can be seen how rapidly the life of a lamp decreases, with only a slight increase above the rated voltage. The increased efficiency is insufficient to pay for the shorter life. The efficiency of incandescent lamps is usually stated as a consumption of so many watts per c. p., and equals the number of watts consumed by the lamp divided by the number of candles given by the lamp; thus, if a lamp consuming 52 watts yields 16 c. p., what is its efficiency?

Solution: Since the efficiency equals the number of watts divided by the number of candles, we have: $\frac{52}{16} = 3.25$ watts per c. p., or simply $3\frac{1}{4}$ watts. Although this method is in common use, it is nevertheless incorrect, as a little consideration will show. Instead of giving the efficiency it really gives the inefficiency of a lamp, since the term 3.1 watt lamp or 3.4 watt lamp means that in the first lamp 3.1 watts must be expended to obtain one c. p., while the second lamp takes 3.4 watts per candle; so that although the second lamp has the higher efficiency figure, it is really the lesser economical one. The misnomer is being recognized by the electrical profession, and it would not be at all surprising if a change were effected which would be consistent with other efficiency determinations, viz: That the efficiency of any appliance shall equal the output or work performed by it,

divided by the energy it consumes, or the per cent of intake the device will give out in useful work. If such a change comes to pass the efficiency of incandescent lamps will very likely be stated in candles per watt, or rather fractions of a candle per watt, which is the true method. In such a case dividing the candles by the watts would give the efficiency. Thus, if a lamp gives 16 c. p. while consuming 50 watts, what is its efficiency?

Solution: Since $\frac{\text{candles}}{\text{watts}}$ equals efficiency, we have: $\frac{16}{50} = .32$

candles per watt; the lamp could then simply be said to have an efficiency of 32.

Lamps can be made to give one c. p. per watt, but their life is very short. A lamp yielding 1 c. p. for 3.1 watt energy consumption is considered a high efficiency lamp and has a life of about 600 hours, if the voltage is not increased above the normal; the lamp depreciates very quick even with excesses of pressure of short duration. For this reason high efficiency lamps are used only where the voltage can be maintained constant. The greater the fluctuations of the voltage, the lower efficiency lamps should be used, that is, lamps having a higher consumption per candle. In these lamps the filament is not brought to such a high temperature at the normal voltage, therefore, an increase of pressure does not affect them so much as it does lamps of higher efficiency. Three and a half watt lamps have an average life of about 800 to 1000 hours at the normal voltage. Of course the greater the excess pressure, and the longer its duration, the shorter will be the life of the lamp.

All incandescent lamps bear a small label giving their trade name, the c. p. and the voltage at which they are to operate; it makes no difference in the burning or current consumption whether the lamp be connected to a d. c. or an a. c. circuit, as long as the voltage is right.

There are several kinds of lamp bases in use, the three principle ones being the Edison, T-H and the Westinghouse (Sawyer-Mann); Figure 102 gives a view of the three and needs no explanation, except that in each case the current enters and leaves the lamp through the pieces marked T, T.

Incandescent lamps are made in sizes ranging from a fraction of one, to 150 c. p. Sixteen c. p. is the size in common use and when the size or output of any machine or installation is given as so many lights, sixteen c. p. lights are meant, except, of course, arc machines. Moreover, if lights are mentioned without their capacity being given, 16 c. p. lamps are considered as meant. Standard lamp sockets and receptacles will fit 2-4-6-8-10-16-20-25-32 and 50 c. p. lamps, these being the sizes that are

standard, for commercial lighting circuits. Larger sizes than 50 c. p. are called Mogul lamps and require special sockets. Lamps of less than two c. p. are mounted on miniature bases; they are not made for standard voltages of lighting circuits, being supplied by batteries. When it is desired to burn them on a regular lighting circuit a number of them must be connected in series so that the voltage of one multiplied by their number equals the line voltage. The smaller size lamps are used principally for display and decorative lighting and sign work. Lamps of the sizes given

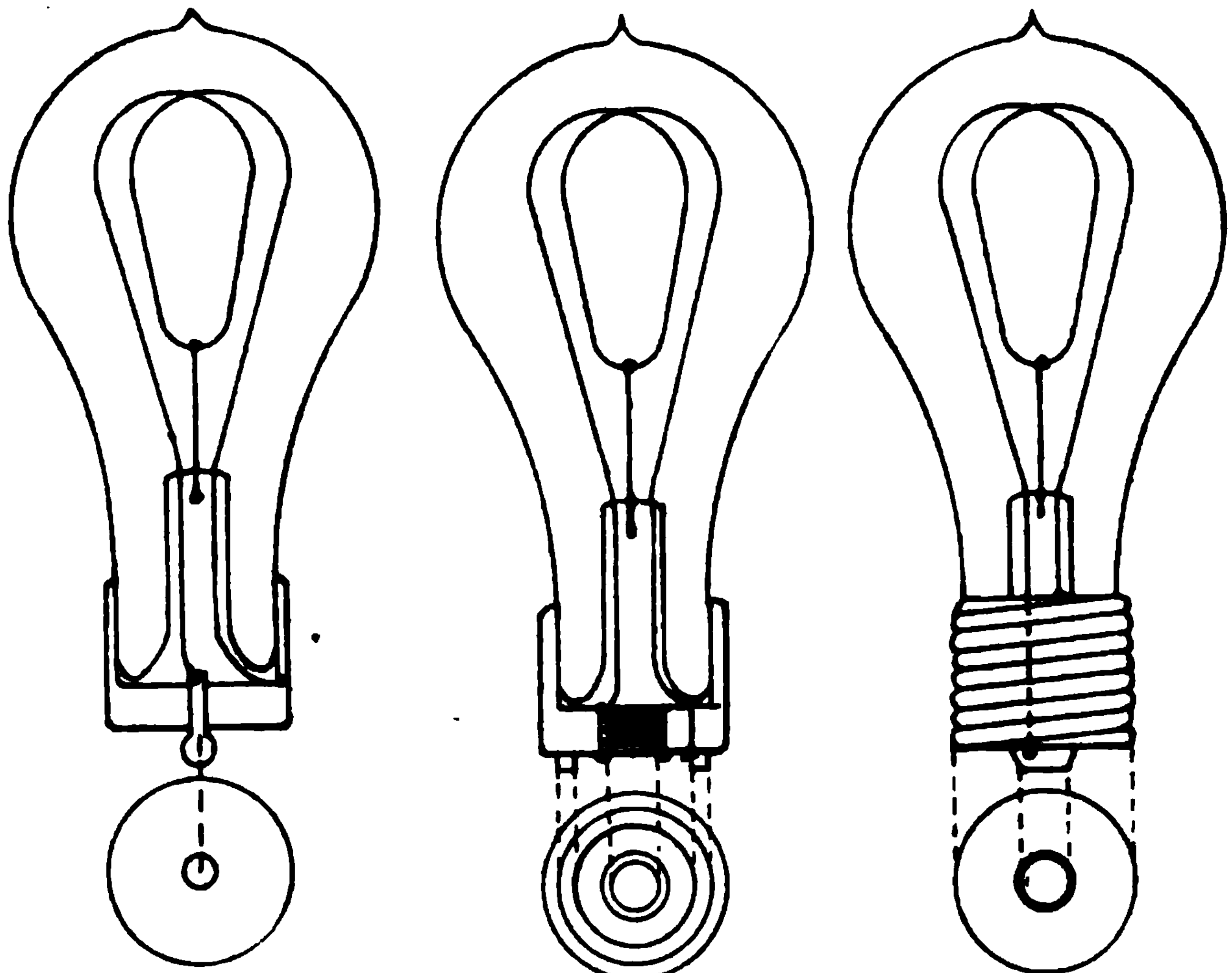


FIG. 102.

above can be obtained to operate on voltages from 50 to 75, 100 to 110 and 200 to 220 volts. In ordering lamps it is necessary to state the voltage, the wattage, the style of base, the c. p., the shape (if other than pear-shape is wanted) and the trade name, if one has any preference.

There is a type of incandescent lamp, which has come into prominence recently, called the "Nernst" lamp. It is an incandescent lamp but does not require a vacuum for successful operation. It is named after its inventor, Dr. Walther Nernst, a German scientist. The light-giving element, called the glower, is made of a material capable of withstanding high temperature readily. This material, its exact nature being known only to the manufacturers, possesses the property of being a non-conductor when cold, but becoming conductive when brought up to incandescence. Therefore some heating device is necessary to start the

lamp. As soon as current flows through the glower the heater is no longer required, the current then serving to keep the glower hot. Heating the glower is effected by a pair of heater-tubes, see Figure 103, heated electrically. Below the two heater-tubes, at a distance of $^1/_{16}$" the glower is mounted. If farther away than this it will take too long to start the lamp, and if the glower is too near the heater tubes the latter will be rapidly destroyed by the intense heat of the glower. As soon as current begins flowing

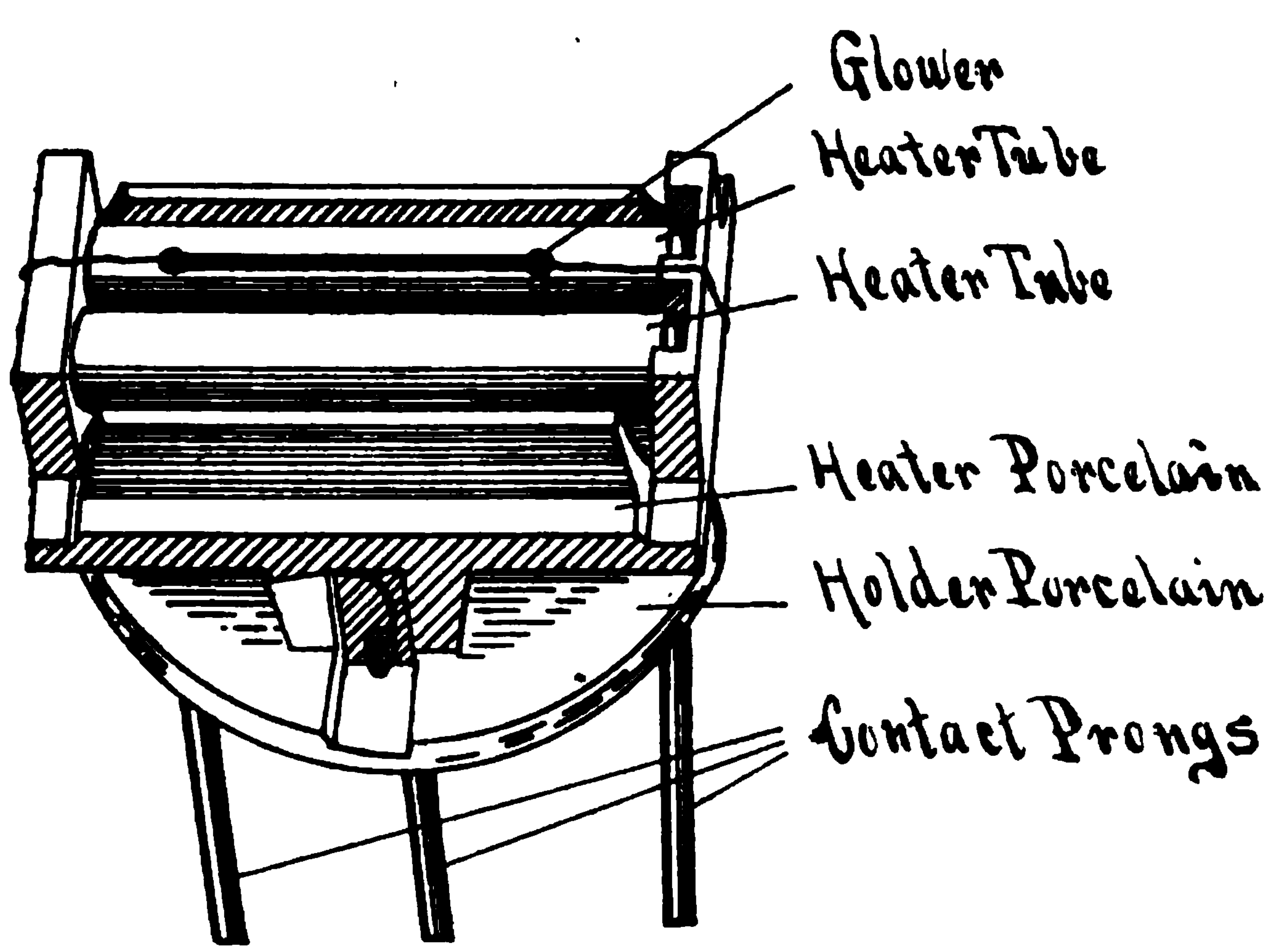


FIG. 103.

in the glower it will come up to brilliance very quickly and the heater-tubes are then no longer necessary and they are cut out of circuit automatically. As the glower has a negative temperature —coefficient, that is, since its resistance decreases with a rise in temperature, it is clear that some precaution must be taken to keep the current within a certain limit. For this purpose a steadying resistance or ballast is connecting in series with the glower. The resistance of this ballast of course increases with a rise in temperature and thereby partially neutralizes the reduction of the glower resistance. Figure 104 is a diagram of the connections of glower heater-tubes and ballast, also showing the cut-out. Up to the present Nernst lamps are made for a. c. circuits only. In the 100-110 volt type they are made in single

glowers only, but in the 220-volt type they are made with one, two, three, four, five and six glowers. Each glower gives 50 candle-power. The light is remarkably steady, soft and agreeable to the eye, and is white in color. The efficiency is very high, being virtually double that of the average incandescent lamp. The current consumption of a single glower lamp is 88 watts and the light given is 50 c. p., therefore the watts per candle are 88/50= 1.76, as against 3.1 watts in the best incandescent lamps. Further, the Nernst lamp is not readily affected by voltage fluctuations, a 10 per cent variation, that is 5 per cent above or below normal, not causing a perceptible variation in the light, nor does it greatly reduce the life of the glower, whereas a 5 per cent rise in voltage would shorten the life of an incandescent lamp nearly 63 per cent. Glowers used on 220 volt circuits have a much longer life than those used on 100-110 volts. The average life of a glower is 800 hours, of the ballast 2500 hours and of heater-tubes 200 hours. The latter, however, does not mean lamp-hours but actual number of hours that the heater is in circuit, and when it is considered that the heater is in circuit only from 45 seconds to one minute every time the lamp is lighted, it will be readily seen that the heater-tubes will outlast a number of glowers. Single-glower

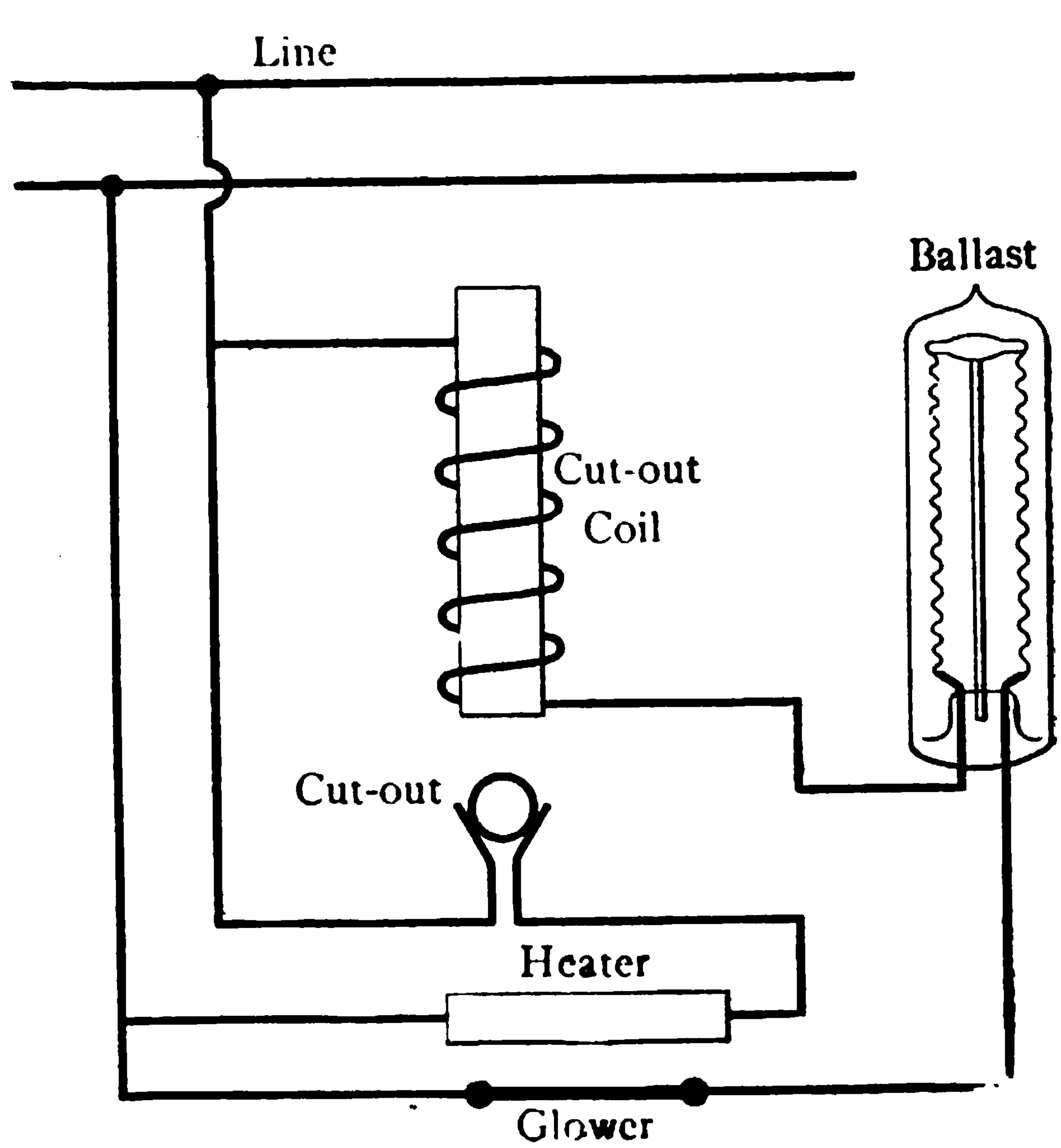


FIG. 104.

lamps are made to screw into standard Edison sockets. The lamp is made for in and out door service and is graceful in design, see Figure 105.

FIG. 105.

CHAPTER XV.

ARC LAMPS.

The operation of arc lamps depends upon the fact that when a sufficiently strong current is flowing through two carbon pencils whose ends are in contact, a number of sparks pass from one carbon to the other when the two are separated. These sparks, or flame thus produced, have a very high temperature and give an intensely brilliant light.

In the early days of arc lighting only direct or continuous currents were employed; therefore we will consider d. c. arc lamps first, and use a d. c. lamp to illustrate and explain the general principles of arc lighting.

Any conductor of high resistance is more easily heated than one of lower resistance, in fact can be heated to a white heat at a comparatively low current density. When two carbons whose ends are in contact are carrying a current, of say nine amperes,

no effect will be noticed except a slight reddening of the carbons at the point of juncture (especially if the contact be a loose one) until they are drawn apart, at which instant the current will produce a flame between the two ends. The gap is the high resistance and is heated by the passage of the current. The positive carbon will also be intensely heated at the point where the flame touches it, thereby being vaporized. The current carries the vapor across the gap onto the end of the negative carbon; the vapor then forms the path for the current and is thereby heated

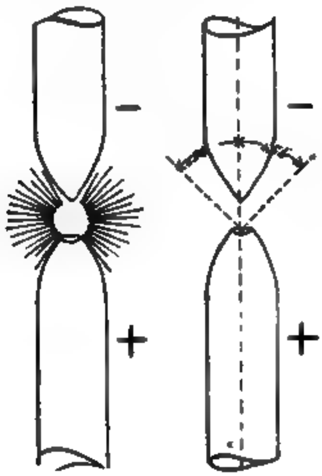


FIG. 106. FIG. 107. FIG. 108.

to a white heat. The path of the vapor from one carbon to the other is not straight but is curved slightly, forming an arc of a circle, Figure 106, hence the name arc lamp. It is not the arc itself, however, that produces the illumination. As already stated, the point of the positive carbon where the arc makes contact with it is heated to the boiling point, thus causing it to become slightly cupped or hollowed out, which hollow is called the crater, Figure 107, and the crater is the seat of illumination. The arc and the negative carbon give very little light, as compared to the crater, although each is at a very high temperature. The light does not travel out in a horizontal direction, but by far the greater portion is emitted away from the positive carbon at an angle of 90 degrees with its axis, see Figure 108; therefore the lamp is always connected so that the upper carbon is positive, which results in shedding the light downward.

If the carbon is pure the current strength does not affect the whiteness of the light shed by the crater. The heavier the current, however, the larger the size of the crater. The crater is incan-

descent, that is white hot over its entire surface, hence, the greater its surface the more light it will emit. The amount of light, then, depends on the current strength. The quality, or the color of the light depends on the material of which the electrodes consist, that is whether they are of carbon or other substance; also whether the arc is surrounded by air or other gas. An arc between electrodes of copper is green, white between those of zinc and bluish white between carbons. The reason for the extensive use of carbon for arc lighting is its great durability and comparatively low cost, besides the quality of its light. Authorities differ on the actual temperature of the arc. They all agree, however, that it is the highest artificial temperature known; it is considerably over 3000° C. Being so high renders accurate determination exceedingly difficult, hence the varying statements.

Since the upper carbon is the one that is vaporized, it is consumed faster than the lower one, burning away about twice as fast as the latter. As the carbon burns away the length of the arc increases, thus increasing its resistance, hence reducing the current strength and thereby the size of the crater, which also reduces the amount of light emitted. The carbons must therefore be moved nearer together. This, and also starting the arc, is done automatically by the feeding or regulating mechanism, usually located in the upper portion of the lamps, see Fig. 109. A magnet, M, is connected in series with the carbons, and its armature, A, lifts the upper carbon by means of a clutch, C, when current is flowing, thereby striking the arc. Another magnet, S, wound with fine wire is connected in shunt across the two carbons and series coil, hence the percent of total lamp current through it depends directly on the length of the arc; the longer the arc the more current through S, and, therefore, the stronger its pull; the pull of the series coil, M, will also be weakened as more current goes through the shunt coil. The latter acts on the same armature that M does, and is connected to oppose the pull of M. Therefore as the carbon burns away and the arc becomes longer the increased resistance of the arc causes a greater drop between the two carbons, hence, forces more current through S and enabling it to pull the armature, A, away from M; as soon as the carbons are again at their proper distance the pull of S weakens, hence, can move the armature no further until the carbons burn away some more, when it will feed again. As the range of the armature is limited, a point is soon reached beyond which the carbon cannot be fed by this arrangement alone. Therefore a tripping post, T, is provided, which, when the armature has reached a certain point in its downward course, releases the clutch, which permits the carbon or carbon rod, R, to slide through the clutch. This feeding of the carbon shortens the arc sufficiently to so weaken the shunt coil that the series coil can draw

the armature through the entire range of its travel. The same set of operations is then repeated over again if the lamp is kept burning. The point of release of the clutch is usually made adjustable. An adjusting spring, S, is also provided, against which the shunt coil must pull to feed the lamp; by this means any desired length of arc can be obtained. As a rule, lamps are adjusted before they are sent out from the factory, and are set at

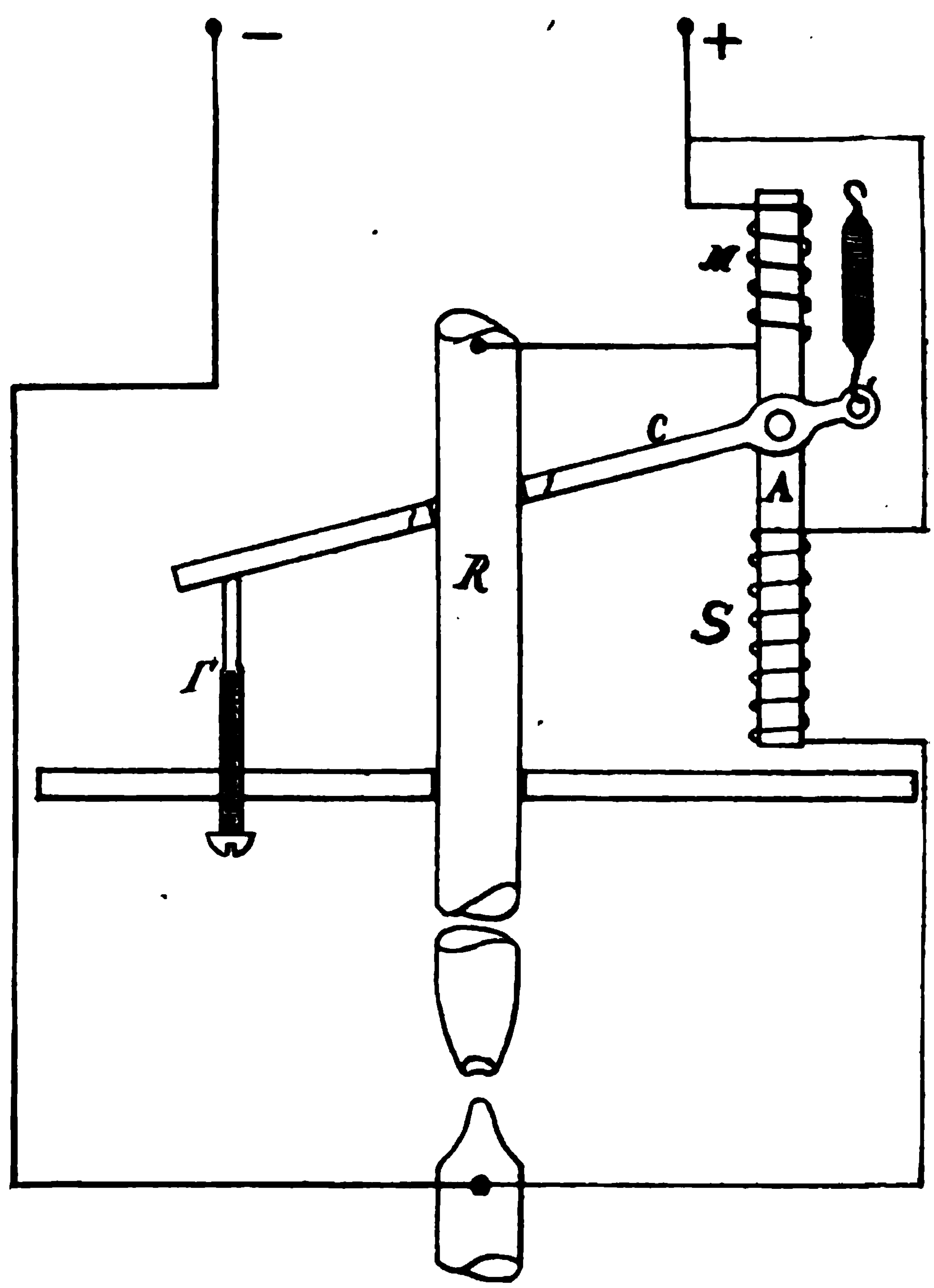


FIG. 109.

the best point by men having especial skill in such work. It is thereby poor policy to change the adjustment because a lamp don't work just right; cleaning the rod or blowing the dust out of the mechanism will generally remedy the trouble. The figure is not a view of any particular lamp but a diagram of arc lamps in general, showing the principle of their construction. Some of the older types of lamps feed by means of a rack movement, the rod having

teeth throughout its entire length. A pinion engages these teeth, the pinion forming a part of a system of gears held and released by the shunt and series coils as in the clutch-feed lamp. Other lamps are arranged to feed both upper and lower carbon at the same time, thus holding the arc always in the same position. The principle is the same in all, however, therefore no further description will be given, especially as there are such a great number of good lamps on the market. What differences there are, are only in detail of construction.

Arc lamps for general illumination have a rated capacity of from 1000 to 2000 candle-power, but those used for search-lights, etc., have a much greater capacity.

Arc lamps are of various classes. As to the circuits they are used on they are either constant-current (series) or constant-potential; as to kind of current they are to burn with, they are a. c. or d. c. They are also divided into open or inclosed arcs, according to whether the air has free access to the arc or whether the former is excluded from the latter.

The D. C. Series Open Arc was the first type of arc lamp in use and is extensively used even yet, but is losing ground. In this type of lamp the length of the arc is from 3/16 to 1/4 of an inch and the voltage across the terminals is about 45 to 50 volts, while the voltage of the arc itself is about 39 or 40 volts. It is generally made in 1200 and 2000 c. p. capacities, the former taking 6.8 and the latter 9.6 amperes. They are connected in series with the line, hence the total voltage of the line will be the voltage of one lamp multiplied by the number of lamps in circuit. Fifty volts is usually taken as the voltage of one lamp in such a calculation. As the current strength is the same throughout the entire circuit it follows that a 1200 c. p. lamp cannot be used on a circuit of 2000 c. p. lamps, as the latter take 9.6 amperes, while the former takes only 6.8 amperes; the series coils of a 1200 c. p. lamp would be burned out in a short time if such a lamp were connected to a 2000 c. p. (9.6 ampere) circuit.

As this lamp burns on a series circuit, evidently if the circuit should be opened in any way, as, for instance, by the burning out of the carbons, the carbons failing to feed, falling from their holders or being broken in any lamp, all the lamps on the circuit would go out. To prevent such an occurrence each lamp is provided with a device which automatically cuts out the lamp, that is, closes a circuit between the two lamp terminals, in case the circuit opens anywhere in the lamp mechanism. The diagram, Figure 110, shows the arrangement; K, is the cutout magnet and is in series with the series magnet and carbons. Therefore, when current flows through the lamp the cutout magnet can pull up its armature, which, when down permits the current to pass from one terminal direct to the other without

going through the carbons. A resistance, R, about equal to that of the series coils and carbons (exclusive of the arc) is generally connected in this cutout circuit, as, if this were not done, no current would flow through the lamp when the armature of K is down, owing to the high resistance of the lamp compared to that of the cutout circuit; therefore, the lamp could not start burning, even when in good order otherwise, until the armature of the cutout were raised by hand. With the resistance in the cutout circuit, however, about half the current goes through the lamp when cutout is closed, if the lamp circuit is closed, and that is sufficient to enable the magnet K to lift its armature and open the cutout circuit.

As in these lamps one set of 9/16x12" carbons would burn out in about eight hours, and it is necessary in some cases that

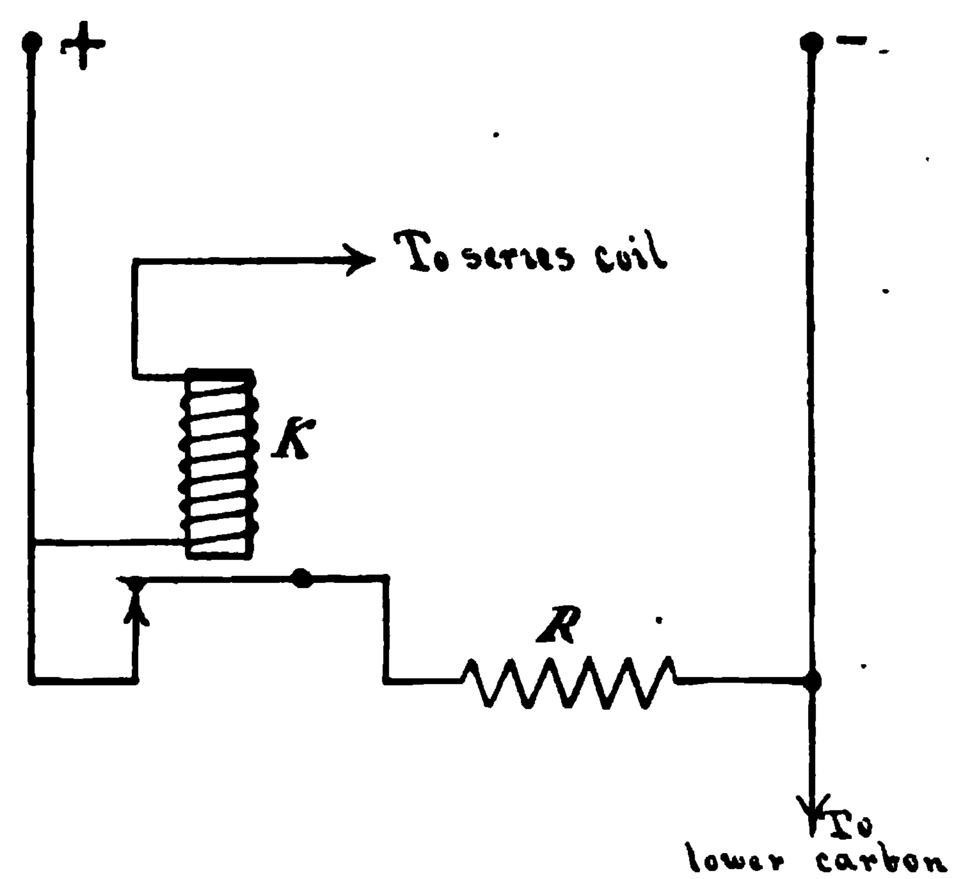


FIG. 110.

they burn longer with one trimming, some of them are made with two carbon rods and carbons, the one set not being able to feed until the other set is burned out.

In connecting a d. c. series arc lamp to a circuit it is necessary that the connection be so made that the upper carbon be positive; that being the one that burns the faster, and hence is longer than the other, and also being the one from which the light is emitted. In most lamps the positive terminal connects to the coils and the negative terminal connects direct to the lower carbon holder by means of a wire runing down on the frame of the lamp. If the lamp should be connected wrong (upside-down as it is called), the lower carbon would be positive and would burn away faster so that in a few hours the carbon holder would commence burning; the light would be cast upward

instead of downwards, owing to the crater being on the bottom carbon. When a lamp is burning it is a simple matter to tell whether it is connected right or not; all that is necessary is to switch it off for a few moments, and it will be noticed that one of the carbons, the positive one, stays hot considerably longer than the other. Therefore, if the lower carbon remains hot longer than the upper, the lamp is connected wrong and must be reversed.

In handling these lamps on live circuits considerable caution should be used, especially if out-of doors or anywhere where one can come in contact with the ground through an iron pipe, beam or column or a wet floor, as the circuits on which they operate are always more or less grounded, and a shock, owing to the high voltage employed, might prove fatal. It is not sufficient to close the switch on the lamp itself to cut the lamp dead. Closing the lamp switch merely provides a by-pass around the carbons for the current; they are therefore, just as much alive as if the current were flowing through them. To enable one to cut a lamp dead a switch is provided in the hood with which outdoor lamps are equipped, or in the case of in-door lamps near the place where the wires enter the building, which, as can be seen by Figure 111, disconnects both sides of the lamp from the line besides keeping the line circuit closed.

D. C. Constant-Potential Arc Lamps are connected directly across the two sides of constant potential circuits. Each lamp is, therefore, entirely independent of any of the others on the same circuit, and hence, they need no automatic cut-out like those used on series lamps. In fact they could not work with one, as closing the cut-out would cause a short circuit.

Constant-Potential lamps, however, belong to the inclosed-arc or inner-globe type. That is, there is a small globe over the carbons within the outer globe; the inner globe is secured to the lower carbon holder in such a way as to prevent the entrance of air at this point. Its upper end is ground smooth and covered by a cap having a hole in the center just large enough to permit the carbon to slide through it without sticking. When the lamp burns, the air in the globe is quickly consumed, causing a partial vacuum in the globe. This partial vacuum is maintained because the air cannot readily enter, there being no appreciable opening for it; its entrance is also opposed by the high temperature within the globe. A cross sectional view of the arrangement is shown in Figure 112, G being the globe, H, the lower carbon holder, A, an asbestos washer between the edge of the globe and H; R is a ring which screws on over the outside of H, forcing a spiral spring, S, which encircles the globe against the slanting surface of H. The spring being thereby compressed to a smaller diameter than the edge of G, a few turns will seat the

edge of G firmly on the washer A, thus making a practically air tight joint. In the plate, P, at the upper end, will be noticed two small grooves, g, g; the surface of the plate rubbing against the carbon is thereby reduced and the hot air, in rising upward, forms eddies, which tend to prevent the entrance of cold air. Another arrangement is shown in Figure 113. The advantage of the in-

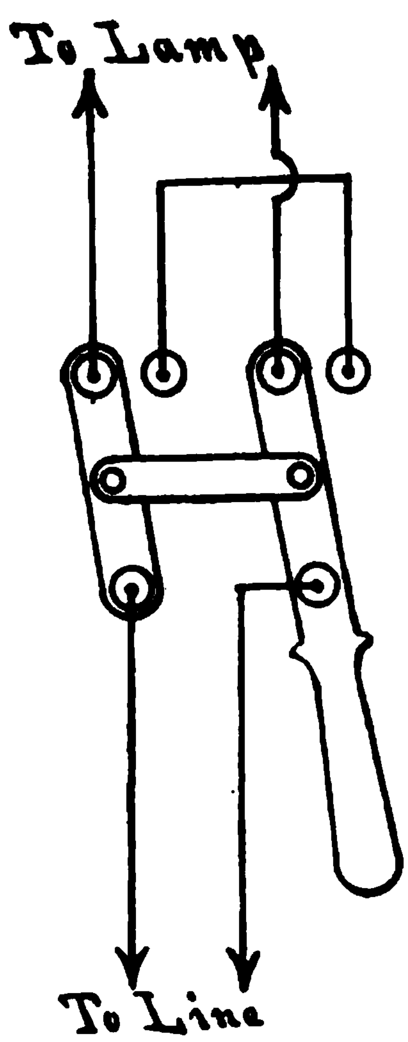


FIG. 111.

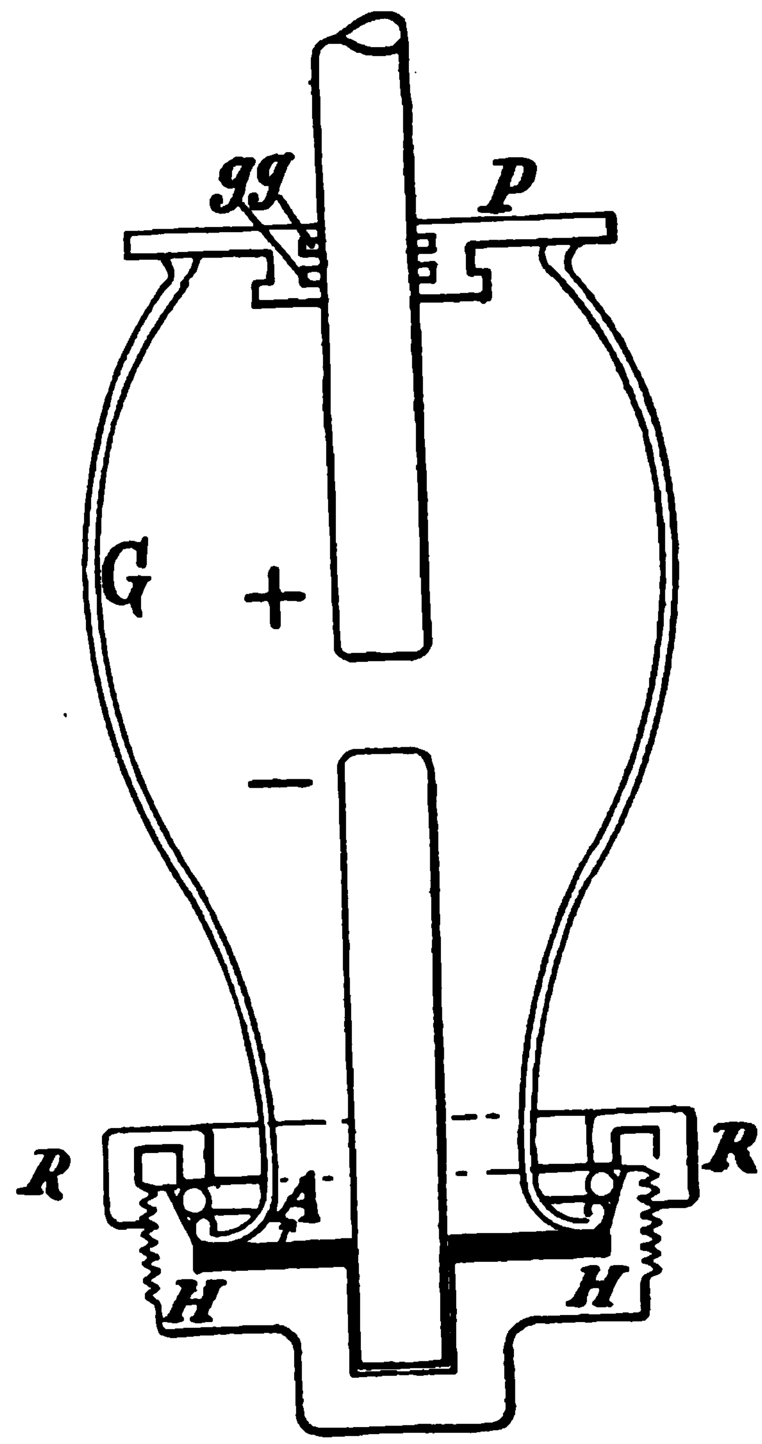


FIG. 112.

closed-arc over the open-arc lamp lies in its greater economy, as it takes much less carbon; one set will burn from 100 to 200 hours. Also, since the carbons are consumed so slowly the lamp feeds only at long intervals, resulting in a very steady light. There is, moreover, no danger whatever of a fire being caused by flying sparks from the arc.

The reason that the open arc burns the carbon away so fast is because the air has free access to the arc, thus supplying the latter with plenty of oxygen, causing rapid combustion. For that reason a short arc must be used on open arc lamps; if the arc be made longer than say one-fourth of an inch, not only will the life of the carbons be greatly shortened, but the light will also be re-

duced considerably, and without a corresponding saving of energy. The voltage of inclosed lamps is from 75 to 85 volts and the arc is from three-eighths to seven-sixteenths of an inch. The air is not entirely excluded from the arc, but is nearly so. A little air enters continuously through the space between the upper carbon and the plate. This small supply of oxygen is necessary to unite with the carbon thrown off by the arc, thereby forming a gas which don't interfere with the light. Were no oxygen present the carbon would coat the inside of the globe with black soot in a short time, thus shutting off the light. There is a deposit on the globe anyway, caused by impurities in the carbons; as it is of light color, however, it does not diminish the light emitted from the lamps, as long as it is not allowed to become too thick.

Very hard carbons are used in these lamps, generally known as pressed carbons. Some carbons are made with a soft core which are used chiefly on a. c. inclosed lamps. The core having

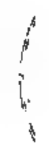


FIG. 113.

the higher conductivity, the current, and hence the arc, is held in the center, and is thereby steadied. From four to six amperes is the average current consumption. They will burn from 100 to 200 hours with one trimming, depending on the length of arc and the current intensity.

Most of them have series coils only, as, being connected to the circuit in parallel, the current through the shunt coil would be wasted. When no current flows, the carbons are in contact, being picked up by the armature of the series magnet when current comes on. As the carbon burns away the resistance of the arc increases, which reduces the current and hence, weakens the magnet and allowing the pull of a spring or gravity to feed the carbon. As the voltage of the ordinary lighting circuits on which they are used is from 100 to 110 and the voltage of these

lamps is only 85, a resistance is placed in series with each lamp, the drop in which cuts down the voltage to the desired value. They are used chiefly for interior illumination and are therefore provided with opal outer and inner globes, which, although cutting off considerable of the light, render the same more agreeable to the eye and by thoroughly diffusing it, eliminate all shadows cast by parts of the lamp frame. The carbons used should be free from impurities, as the latter cause a deposit of sediment on the inner globe which cuts off the light.

What has been said of d. c. series and d. c. constant-potential lamps applies, respectively, also to those used on a. c. series and a. c. constant-potential circuits, but with some modification. Both kinds of a. c. lamps mentioned are of the inclosed-arc type; their magnets differ somewhat from those used in d. c. lamps in order to better adapt them to a. c. circuits, but in general they are the same. Of course, owing to the continual reversing of the current the crater is not confined to one carbon but is formed, to a certain extent, first on one and then on the other carbon; owing to the short duration of the current in any one direction the crater can never attain anywhere near the same proportions that it does in the d. c. lamps. If the carbons are in a horizontal position their consumption will take place at an equal rate; when in a vertical position the upper one burns away about 8 or 10 per cent faster than the lower one.

A. c. constant-potential lamps are equipped with a reactance coil connected in series with them; its function is the same as the resistance in the d. c. constant-potential lamp, but it accomplishes its purpose without waste of energy, unlike the latter. The line voltage is reduced by the e. m. f. of self-induction or the inductance of the coil, hence there is no waste of energy. The coil is divided in sections, and by a change in the number of sections cut in the effective voltage at the arc can be varied.

Series a. c. lamps are used for street or out-door lighting exclusively, and are beginning to supplant the old d. c. series open arc for this class of service, just as the open constant-potential lamp had to give way to the inclosed type for interior service. There is a great saving of labor effected by the use of the inclosed arc lamp, as a lamp burning say, 10 hours a night needs to be trimmed but twice, or at most, three times a month, whereas the open arc would have to be trimmed every day.

Inclosed arc lamps should be suspended at a height of not exceeding 20 feet from the floor or the ground, to obtain the best illumination.

CHAPTER XVI.

STORAGE BATTERIES.

A storage cell consists of two plates immersed in a solution of dilute sulphuric acid contained in a suitable vessel. The vessel used for portable cells being made of hard rubber or ebonite, while those for stationary cells are made of glass; the latter enable one to inspect the plates while the cell is in action. A number of cells connected together are called a battery. A storage cell can deliver no current until it has been charged, that is, has had a current passed through it from some source. When charged and disconnected from the charging circuit it will set up a current in an opposite direction to that of the charging current if the two plates be connected together. The plate at which the current enters while charging, is always called the positive plate.

The plates consist of a more or less open frame work of lead, called grids, the openings of which are filled with the active material which consists of either minium, lead oxide, peroxide of lead, lead sulphate or some mixture thereof. This active material is either in the form of a paste or a dry powder. In the latter case it is forced into the openings of the grid under such a great pressure that it becomes a solid mass. If a paste is used the substance used for the positive plates is mixed with water, while the paste for the negative plates is mixed with sulphuric acid. In order that the active material be held securely in place the interstices in the grids are made either larger or smaller in the center than at the outside edge, as shown in Figure 114, this

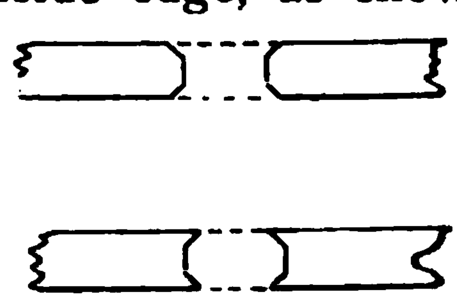


FIG. 114.

resulting in a sort of dove-tail which prevents a falling out of the active material. The solution in which the plates are immersed, called the electrolyte, contains one part of sulphuric acid to four parts of water when the cell is first set up. During the charge sulphuric acid is formed and when the cell is fully charged the amount of the acid is about one to three parts of water, that is a 25 per cent solution, while at first it was only a 20 per cent solution. The latter has a specific gravity of about 1.17, while that of the 25 per cent solution is about 1.22. The charging current decomposes the water, the oxygen of which changes the lead oxide at the positive plate into lead peroxide; the hydrogen re-

duces the active material on the negative plate to a spongy lead and forms sulphuric acid. When the cell is fully charged the negative plate is of a gray or slate color, while the positive plate is brown. At this stage the cell begins giving off bubbles of air and is said to be "gasing" or "boiling." Continuing the charging beyond this point is a waste of energy, though, unless allowed to continue too long, it does no great harm to the cell. The action of the excess current is to decompose the water, which produces hydrogen and oxygen which pass off in the shape of the bubbles already mentioned.

If the cell is now disconnected from the charging source and connected to some other closed circuit a current will flow, but opposite in direction to that of the charging current, flowing out from the positive plate or the plate at which the charging current entered. This flow of current produces a chemical action in the cell, decomposing some of the sulphuric acid and reducing the peroxide of lead on the positive plate into a lead oxide, and the spongy lead on the negative plate into lead sulphate; that is, the cell has a tendency to return to the original state in which it was before charging. Another action is the formation of a small amount of lead sulphate from the lead oxide at the positive plate. If the discharge is not carried too far there is no bad result. Discharges can be carried on until there is no further action but will result in the formation of white sulphate crystals, which adhere strongly to the active material and when removed carry some of the latter along. Their removal is necessary as they greatly increase the internal resistance of the cell. When a cell is in such a condition it is said to be "sulphated" and the plates will be covered with a white coating. A cell should never be set up until everything is in readiness to begin charging at once, nor should a battery remain in a discharged condition, as sulphating is very apt to result.

The voltage of a single cell is 2.5 volts when fully charged. No cell should be discharged below 1.8 volts and the rate of charge, as well as discharge, that is, the number of amperes flowing, should never exceed the amount recommended by the manufacturer. If the discharge rate is greater than it should be, especially if done continually, buckling of the positive plates is liable to occur. This is due to the unequal expansion of the active material and the grid. As the grids are stronger at their edges than in the center the resultant pressure causes the plates to bulge in the center, sometimes so much that they touch the negative plates, thus short-circuiting the cell. The discharge rate depends on the amount of active material exposed to chemical action and is about .035 ampere per square inch of positive plate surface. In order to get a large area of active surface a cell may be made with a number of both positive and negative plates,

connected in multiple, but there should always be one more negative than positive plates, so that each of the latter shall have a negative plate on each side; the e. m. f. of such a cell will be the same as that of one having but two plates. By connecting a number of cells in series, that is, positive of one to the negative of the other, any desired voltage can be obtained.

It should be distinctly understood that a storage cell or battery stores *energy, not electricity*. The passage of an electric current through a cell produces certain decompositions and the resulting elements and formations tend to reunite by virtue of their chemical affinity, this effort at reunion producing an e. m. f. This reunion, however, can not take place unless, by closing the circuit between the two plates or sets of plates, current flows from one to the other.

As already stated, the voltage of a fully charged cell is 2.5 volts. As soon as discharge begins, however, the voltage falls to 2 volts in the first fifteen minutes or so, but after that the falling off of the voltage is much less if the discharge rate is normal, reaching 1.8 volts in about ten hours. If the discharge rate is greater than the normal the voltage will drop to 1.8 much sooner. The rating of storage batteries is based on a discharge to 1.8 volts in a period of ten hours. The rate of charging should be the same as the normal discharge rate, though it can be less, but in that case the charging must be continued for a longer period of time. During the charge some of the water is evaporated, hence fresh water should be added from time to time, so that the plates shall always be covered by the electrolyte. The water should be put in by means of a hose or syringe reaching to the bottom of the containing vessel; if simply poured into the jar the water will remain on top, being considerably lighter than the electrolyte. By introducing the water from the bottom it will tend to rise and in doing so readily mixes with the solution.

The plates should not rest on the bottom of the jar or containing vessel. Two strips of wood, preferably of triangular shape, should be placed in the bottom of the jars, and on these strips the plates rest, being thereby held about an inch or so from the bottom. This is done to prevent the cells from being short-circuited by loose active material falling from the plates. Were the latter resting on the bottom of the jar the falling particles would very soon cause a short circuit, but by raising the plates the particles can settle on the bottom without touching them. The strips should be boiled in paraffine, to prevent their absorption of moisture.

Storage batteries should be located in a dry, well lighted and ventilated battery room of low temperature, as the warmer the room the greater will be the evaporation of water from the electrolyte. The floor should be stone, brick, tile or cement; if

a wooden floor is used it should have a lead covering. All metal work exposed to the acid fumes should be of lead, or if some other metal is used it should be painted with acid-proof paint. Large batteries are usually set up in lead-lined wooden tanks mounted on insulators. The best way to make connections between the various cells is by the process called lead burning. The parts to be connected are scraped clean and after being placed together are exposed to a flame of hydrogen gas. The hydrogen flame does not oxidize the lead, but considerable skill is required to properly manipulate it, as the lead is easily burned or melted. Hydrogen gas is produced by placing zinc into a vessel containing sulphuric acid; the gas, after being passed through a vessel of water, is conducted to the burner; an air blast is needed to furnish the requisite amount of oxygen for combustion.

The sulphuric acid used in the electrolyte of storage cells should be chemically pure and should be the kind made from sulphur; that made from pyrites is not fit for this purpose. The ordinary sulphuric acid of commerce contains a number of impurities, as hydrochloric and nitric acid, iron, arsenic, copper, etc., which are injurious to the plates. When mixing water and sulphuric acid, the acid should always be poured into the water; *never* pour water into the acid. The mixture generates considerable heat, hence the acid should be added to the water in small quantities. The solution should be mixed at least ten or twelve hours before being used, or preferably, be mixed the day before it is intended to be used.

To charge a battery about two volts per cell are required, which amount gradually rises as charging proceeds, being about 2.6 volts when charging is completed, that is, when "gasing" or "boiling" begins. When a battery is charged the first time the charging should continue considerably longer than the discharge time at normal rate. Overcharging a battery that has been in service is beneficial if done at a low rate and not continued too long, but it reduces the efficiency. Bubbles will commence appearing at the plates before the charge is completed, and when this occurs the charging should continue at a reduced rate as the active material can not absorb all the gas liberated by the flow of current. The amount of gas liberated is always proportional to the current flowing, hence, reducing the latter also reduces the former.

A battery must be charged at least twenty-five or thirty times before it will give its full capacity, and it should be overcharged from twenty to twenty-five per cent at nearly normal rate for eight or ten weeks after being put in service. The best indication of the condition of a cell is the specific gravity of the electro-

lyte, which can be ascertained by a hydrometer. The electrolyte should be stirred occasionally because it is denser at the bottom than at the top. This is because the sulphuric acid formed by the action of the charging current settles on the bottom, it being heavier than the electrolyte.

When testing the voltage of a battery the cells should also be tested individually, and if any of them are of a much lower voltage than the others they should be taken out and overhauled. Any direct current source can be used for charging, but arrangements should be such that the voltage can be regulated to suit the number of cells connected together and to increase it as the charging proceeds. This can be accomplished by starting the charging with a variable resistance in circuit which is cut out step by step. A better means is a generator whose voltage can be varied at will.

Storage batteries have come into very extended use in electric light and power plants. They serve to steady the voltage with large and rapidly fluctuating loads and enable generating units to carry a large overload for several hours, sometimes double their capacity, the batteries being charged during the time of light load and discharging into the line, thus assisting the generator at heavy loads. By this arrangement not only can the generator operate continuously at full load, or nearly so, hence at maximum efficiency, but a much smaller unit can be used than would be required without a battery. Also, in case a shut-down of the engine or generator is unavoidable, the battery can carry the load for a considerable length of time, thus obviating an interruption of the service. They can also be used to regulate the voltage on long circuits.

Where storage batteries are used in electric plants there are usually special arrangements for charging and control. As the generators in such plants are hardly ever capable of having their voltage varied within wide enough limits to charge a battery, a *booster* is employed. This booster is a dynamo, capable of supplying the full charging current and designed for a sufficient variation in voltage. The armature is in the battery circuit while the fields are generally excited by the current from the generator or busbars. Regulation of the battery voltage is obtained by switching in or out some of the cells, which are called end cells or by counter electro-motive-force cells. In the latter case a few cells would be connected in opposition to the battery, a suitable switch enabling one to connect any number of the c. e. m. f. cells into or out of circuit.

CHAPTER XVII.

ALTERNATING CURRENTS.

All electric currents or e. m. f.'s set up by magneto-electric induction are alternating in direction. Recollecting the manner in which e. m. f.'s are set up, viz.: by the altering of the number of lines of force through a loop or coil of wire, we can readily understand why they must be alternating. We have seen how these alternating impulses are commuted or rectified by means of a commutator, that is, made to act in one continuous direction. The laws governing the flow of these direct currents are few and comparatively simple. Alternating currents, however, behave entirely different, hence require to be treated separately.

An alternating current is one which changes its direction continually, starting, say from zero, rising to maximum in one direction, decreasing to zero, then rising to maximum in the opposite direction and decreasing again to zero; this series of events being repeated over and over as long as the current flows. One reversal, that is, a rise of current from zero to maximum and return to zero is called an alternation and two alternations are

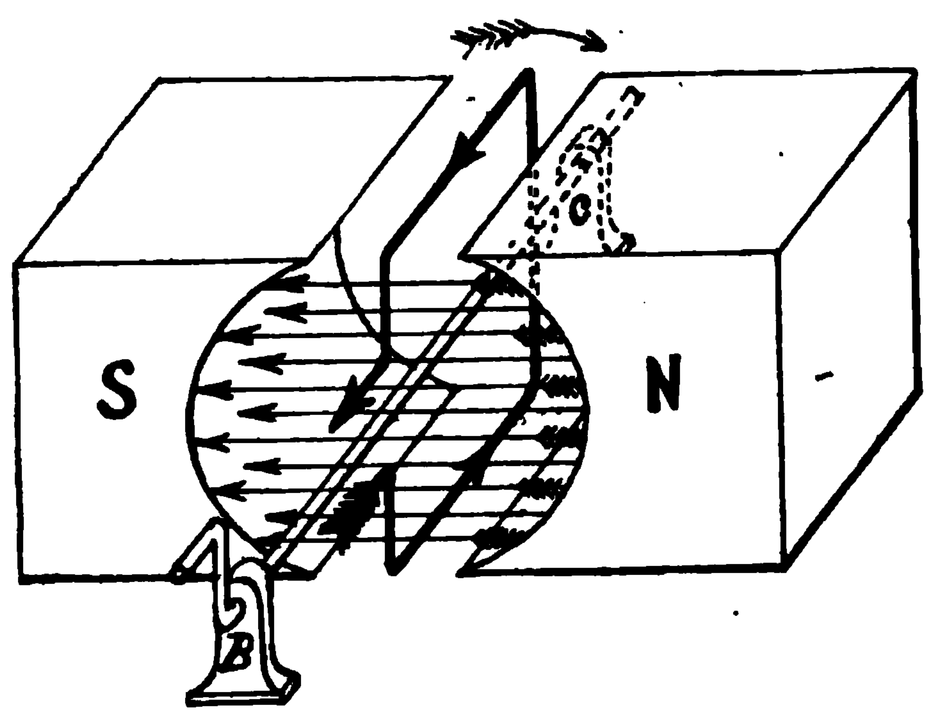


FIG. 115.

called a cycle. The number of alternations or cycles of the current in a given length of time is called the frequency, usually expressed in cycles per second, or alternations per minute, and the length of time taken to complete a cycle is called a period. In the case of the simple loop dynamo, Fig. 115, if the loop were rotated 25 times per second the frequency of the current generated would be 25 cycles per second, or simply 25 cycles, since starting from the position shown, which is the zero position, the side 1 of the coil going downwards, would generate e. m. f.'s acting towards the back, while those in side 2 are acting towards the front. These e. m. f.'s would rise in value and attain the maximum when

the coil had gone through 90 degrees or one-fourth of a revolution, when they would become weaker, having ceased entirely by the time the coil had gone through 180 degrees or one-half a revolution. During the second half of a revolution the same rise and fall of e. m. f. would occur, except that it would be in the opposite direction. In other words, the current would have gone through one cycle, and the number of cycles in any length of time would therefore be directly dependent on the speed of rotation of the loop.

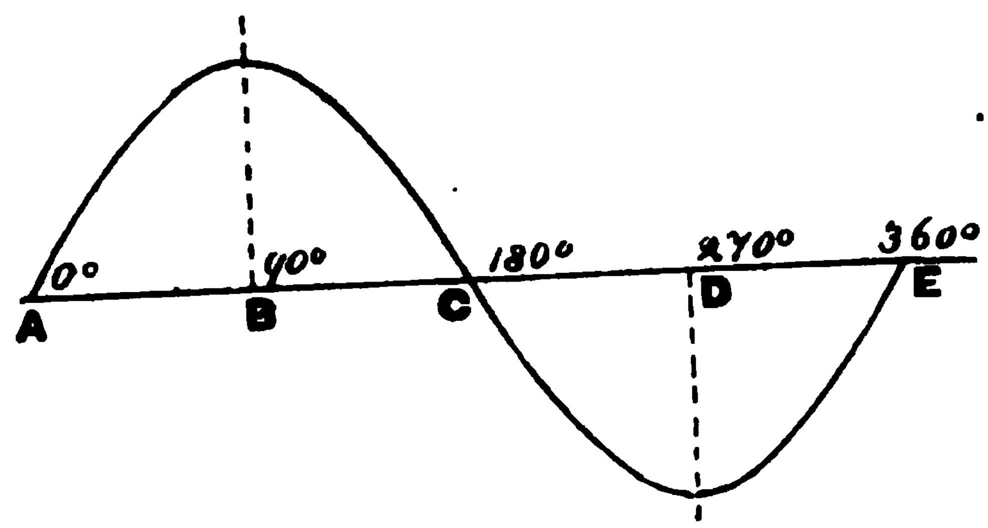


FIG. 116.

Figure 116 is a representation of one cycle, divided into 36 equal parts, each part therefore being ten degrees. The curve A, B, C, D, E, represents the e. m. f. or current, as the case may be, showing its rise and fall, above the zero line and the same change below the zero line, thus indicating that the direction of the latter is opposed to that of the former. Different parts on the curve are said to be so many degrees apart, or one point may be said to be so many degrees ahead or behind some other point on the curve. C, for instance, is 90 degrees behind B, but is 90 degrees ahead of D; A is 90 degrees ahead of B and 180 degrees ahead of C; E, of course, is 360 degrees behind A.

The curve shows that the e. m. f. is constantly varying from zero to maximum and back to zero again, acting first in one and then in the other direction. The value of this e. m. f. at any instant is represented by a line drawn from the curve to the zero line perpendicular, that is at right angles, to the latter. Adding the squares of all the instantaneous values and extracting the square root of their average will give us a certain fraction of the maximum value. This quantity is called the *effective* or *virtual value* and equals .707 of the maximum value. It is also sometimes called the square-root-of-the-mean-square ($\sqrt{\text{mean}^2}$) value. Curves of different shapes will of course give different values of $\sqrt{\text{mean}^2}$ but .707 is near enough for practical purposes.

This effective value is not the average value, as might at first be supposed; the latter is only .636 of the maximum value. From the foregoing we see that the value of an alternating current

or e. m. f. can be expressed in three different terms, therefore it is necessary to know what value is meant in each case, especially when we want to compare the output of a. c. apparatus to that of d. c. apparatus.

The output of a. c. apparatus is always stated in *effective* volts and amperes and a. c. instruments indicate effective values. The effective strength of an alternating current will produce the same amount of heat in a circuit as a direct current of the same strength. The average and the maximum values are rarely used and when they are it is always especially mentioned that the one or the other of these values is meant. The relations between the three values are as follows:

Effective value= .707 maximum value.
Effective value=1.11 average value.
Average value= .636 maximum value.

Dividing the effective value by .707 will show the maximum stress to which the insulation of any piece of a. c. apparatus is subjected.

When two alternating currents or e. m. f.'s have the same frequency they are said to be in *synchronism,* and if they reach maximum and zero at the same instant they are said to be in phase, they may be in synchronism and still be out of phase, but can not be in phase (for an appreciable length of time) without being in synchronism. It frequently occurs that the current in an a. c. circuit is out of phase with its e. m. f., being either ahead or behind the latter. In the former case it is called a leading current and in the latter a lagging current. This phase difference is called the angle of lead if the current is ahead of the e. m. f., and the angle of lag if it is behind the e. m. f. In a non-inductive circuit, as for instance, one consisting entirely of incandescent lamps, the current will be in phase with the e. m. f. In an inductive circuit, that is one containing magnet coils, the current will lag behind the e. m. f., and the amount of angle of lag depends on the inductance of the circuit. Some electrical appliances, as for instance, condensers, tend to cause leading currents. The action of a condenser is to absorb a charge when the voltage is rising, this charge flowing out as the voltage decreases, thus tending to set up a current in the opposite direction before the e. m. f. of the circuit is reversed. A condenser consists essentially of two conductors or sets of conductors separated by a dielectric. Sheets of tinfoil are generally used for the former, being separated by sheets of thin paraffined paper. Alternate sheets of tinfoil project beyond the dielectric on one side and the remaining sheets project on the other side. This is shown by Figure 117. All the tinfoil sheets projecting on one side are connected together and to one leg of the circuit, those

projecting on the other side being also all connected together but to the opposite leg of the circuit, a condenser being always connected in parallel, never in series.

It has already been stated that when a change occurs in the current flowing in any coil of wire the change in current strength produces a similar change in the number of magnetic lines through the coil, and that this induces the e. m. f. in the coil (especially if the coil has an iron core) which either opposes or aids the change, depending on whether the current is increased or decreased. This e. m. f. is called the e. m. f. of self-induction. When the current in the coil is increased the resultant increase in the number of lines of force through the coil induces an e m. f. which acts in the opposite direction to the current flowing, hence opposes the increase. If the current is decreased the e. m. f. produced thereby acts in the same direction as that in which the current is flowing, hence, tends to maintain the strength of the current at its original value and direction, even when the impressed or line e. m. f. has been reversed. The impressed e. m. f., however, quickly overcomes the e. m. f. of self-induction, but it takes an appreciable length of time for it to do so. One might almost say the current in the coil possesses the property of inertia.

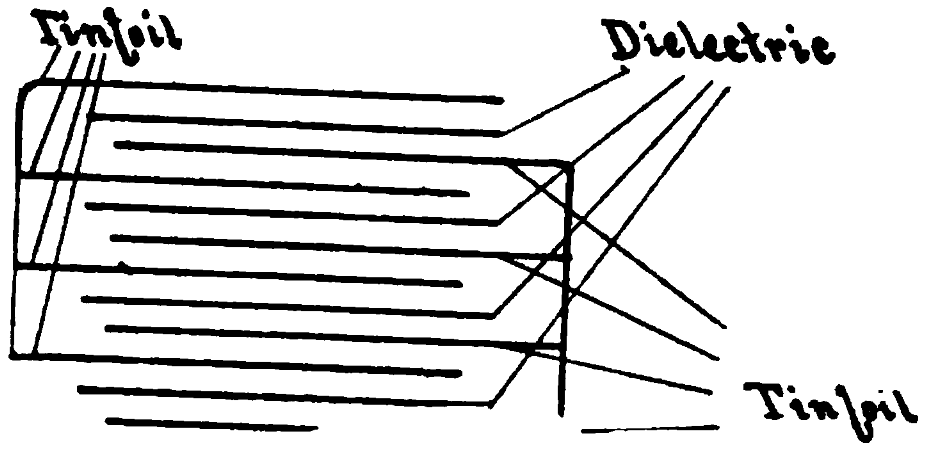


FIG. 117.

The current, therefore, lags behind the e. m. f., and the amount, or as it is called, the angle of lag, usually denoted by the Greek letter θ, (pronounced theta), is proportional to the e. m. f. of self induction of the coil, other things being equal.

Since the magnitude of any induced e. m. f. depends directly upon the rate at which the lines of force in a given coil are cut, and as in the case of the coil carrying an alternating current, the rate of cutting depends on the rapidity with which the change in current through it takes place, it follows, that the higher the frequency of the current, the higher will be the e. m. f. of self-induction. Also, as the cutting of the lines by the wires in the coil is effected by constantly reversing the former, it is clear that the rate of cutting depends not alone on the frequency of the reversals, but also on the number of lines, and as their number, with any given number of ampere-turns, is proportional to the

permeability of the magnetic circuit, it follows that a coil whose magnetic circuit is entirely of iron will have a maximum number of lines set up in it, because the lines in such a case can be set up very readily. This property is called the coefficient of self-induction, or the inductance, the unit of which is the henry, denoted by the letter L. The henry being such a large quantity that it is rarely met in practice, a one-thousandth part, or the milli-henry is the unit mostly used.

The inductance of a coil is constant if the permeability of its magnetic circuit is constant. Where the latter varies the inductance will also vary. In a magnetic circuit containing iron the permeability varies with the degree of magnetization, hence, the inductance varies likewise; however, if the magnetization is not carried too high the inductance may, for practical purposes, be considered constant. The inductance of a coil, therefore, increases its apparent resistance. The resistance of the coil in ohms plus its inductance equals the property called impedance, which latter too are also expressed in ohms. In calculating the flow of current in an a. c. circuit, therefore, the value of the impedance must be substituted for the resistance in the application of Ohm's law. Substituting, instead of current equals

$$\frac{\text{e. m. f.}}{\text{resistance}} \text{ we have: Current equals } \frac{\text{e. m. f.}}{\text{impedance}}$$

The relations between impedance, reactance and resistance are precisely the same as those between the sides of a right-angled triangle, the hypothenuse always being taken to represent the impedance. This is shown by Figure 118; as in a right-angled

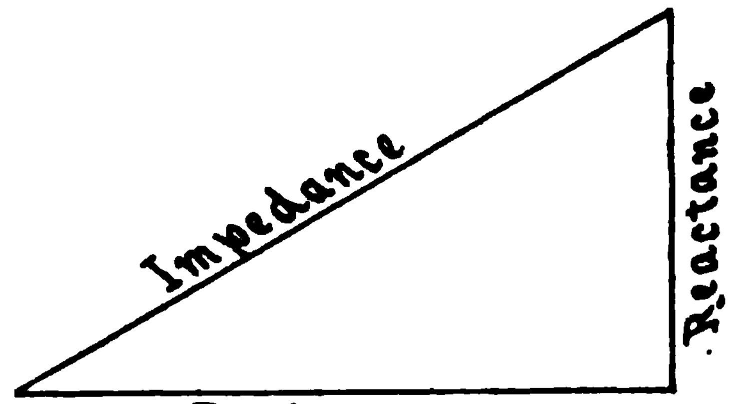


FIG. 118.

triangle the hypothenuse equals the square root of the sum of the squares of the other two sides, so the impedance also at all times equals the square root of the sum of the squares of the resistance and the reactance. The reactance is found by multiplying the inductance in henrys, by twice the frequency (cycles per second) and by 3.1416. The latter number is usually expressed by the Greek letter (π) pi. Expressed by formula this would be: reactance$=2\ \pi$ N L equals reactance$=2\times3.1416\times$frequency$\times$

henrys; N being the number of cycles per second; the reactance being expressed in ohms.

The inductance, L, equals the number of lines through the coil × the number of turns × the current, divided × the 8th power of 10 (10^8) or 100,000,000. In formula this would be:

$$\text{henrys} = \frac{\text{number of lines} \times \text{number of turns} \times \text{current}}{100,000,000}$$

The number of lines equals the m. m. f. divided by the reluctance. The reluctance of a magnetic circuit can be found by dividing its length in inches, by the product of its cross-section in square inches multiplied by its permeability; the latter is usually expressed by the Greek letter μ (pronounced mu). Thus, reluctance equals length (inches).

$$\frac{\text{length (inches)}}{\text{area (sq. in.)} \times \mu}$$

The m. m. f. equals 3.192 × ampere-turns.

The following tables give the values of the intensity of m. m. f., H, the magnetic density, B, per square inch, and the permeability, μ, of gray cast iron, wrought iron forgings, sheets of annealed charcoal iron and un-annealed cast steel; thus, in the table of gray cast iron an intensity of m. m. f. of 105 will produce a density of 20,000 lines per square inch, at which density the permeability is given as 190. Various tables published differ somewhat in the several values assigned to these metals owing to a difference in the quality of the metal tested, two samples of the same metals very seldom being exactly alike. Annealing increases the permeability of metals at low magnetic densities only, and as it is found economical to magnetize cast steel up to and above 70,000 lines per square inch, it is seldom annealed, its permeability at such densities not being appreciably affected thereby.

GRAY CAST IRON.

Intensity of M. M. F. H	Magnetic Density. B	Permeability. μ
64	10000	156
105	20000	190
164	30000	183
262	40000	153
430	50000	116
718	60000	84
1030	65000	63

WROUGHT IRON FORGINGS.			ANNEALED CHARCOAL IRON.		
Intensity of M. M. F. H	Magnetic Density. B	Permeability. μ	Intensity of M. F. H	Magnetic Density. B	Permeability. μ
12	10000	833	16	10000	625
15	20000	1333	23	20000	870
18	30000	1596	28	30000	1071
23	40000	1739	33	40000	1212
30	50000	1667	42	50000	1190
44	60000	1364	53	60000	1132
65	70000	1077	68	70000	1029
104	80000	769	94	80000	851
200	90000	450	138	90000	652
430	100000	233	214	100000	467
630	105000	167	374	110000	294
1035	110000	106	725	120000	165
			1075	125000	116

UNANNEALED CAST STEEL.

Intensity of M. M. F. H	Magnetic Density. B	Permeability. μ
18	10000	555
28	20000	714
35	30000	857
43	40000	930
54	50000	926
72	60000	833
99	70000	707
146	80000	547
225	90000	400
375	100000	266
730	110000	151
1015	115000	113

Power Factor. Whenever current flows in a d. c. circuit the energy expended equals the amperes times the volts; the same is true in an a. c. circuit having no reactance, in which the current and e. m. f. are exactly in phase, as in the case of a non-inductive circuit. Such a circuit is said to have unity power factor or a power factor of one; very few a. c. circuits, however, are entirely devoid of reactance. Nearly all of them have either an inductive reactance or a capacity reactance, some of them having both. These two properties tend to neutralize one another, as already stated, since the former sets up lagging currents and the

latter leading currents. The greater the value of either of these properties when only one is present in a circuit, or, when both are present, the greater their difference, the more the current will be out of phase with the e. m. f. producing it. Therefore, multiplying the indicated volts by the indicated amperes would not give the true watts, because their maximum points do not coincide. The result would be the Apparent Watts, and their ratio to the Real or True Watts would be the same as the ratio of the length of the hypothenuse, A, of the right-angled triangle, Figure 119, to the length of the line B. In this triangle the length of

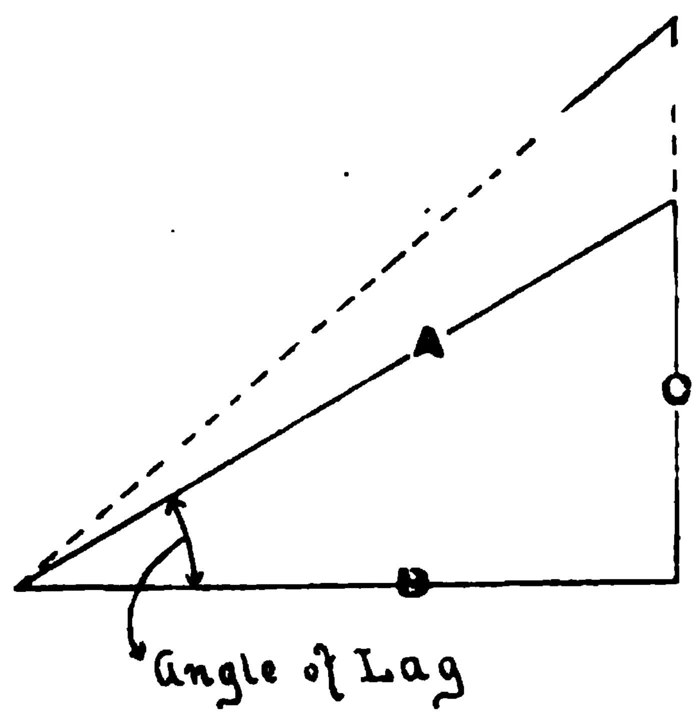


FIG. 119.

the line B represents the resistance of the circuit and the length of the line C the reactance of the circuit, the line A or hypothenuse joining the extremities of the two lines. The angle included between the lines A and B is the angle of lag and becomes greater the longer C becomes as compared to B, as shown by the dotted lines, and the greater would become the difference between the true watts and the apparent watts. This ratio can never be greater than one and may be anywhere between one and zero. It is usually expressed in per cent, that is, any a. c. circuit or appliance is said to have a power factor of so many per cent. Multiplying the apparent watts by the power factor gives the true watts expended in the circuit.

That does not mean that there are not as many amperes flowing as the ammeter indicates, however, but that not all of them are doing useful work. Since a portion of this current represents no energy expended by or put into the generating apparatus it is called Wattless Current. But, you will ask, if the generator is not furnishing the pressure for the flow of these wattless currents, what causes them tō flow? The answer is that they are caused to flow by the e. m. f. of self-induction induced

in the lines or apparatus connected thereto. At first sight one might think that as these wattless currents represent no energy delivered by the alternator they are of no consequence and that, therefore, it makes no difference whether the power factor be high or low. This is a mistaken view, however, as we will see presently. Suppose an alternator to be delivering current to a system whose power factor is 50 per cent. The output or capacity of the alternator is, say, 100 amperes at 1000 volts; its capacity is therefore $100 \times 1000 = 100000$ watts or 100 K. W. Let us now increase the load until the ammeter shows 100 amperes to be flowing, the machine being a constant-potential one, of course the voltmeter will indicate 1000 volts at any load within the capacity of the machine. When the current has risen to 100 amperes there will be flowing in the system $1000 \times 100 = 100000$ watts, which is the full load capacity of the alternator.

The power factor of the system is 50 per cent; and multiplying the apparent watts by the power factor we have $100000 \times$ 50 per cent$=50000$ watts energy delivered by the alternator. From this we see that although the machine is loaded up to its full rated capacity in amperes, nevertheless only a half load is being utilized. It is clear, therefore, that a low power factor is very undesirable, because the alternator could not deliver its full rated capacity in useful watts without injurious heating. Also, since the amperes flowing in a circuit are one of the factors that determine the drop or line loss the latter will be as great at half load as it would be at full load were the power factor unity.

The character of a load on an a. c. system in a great measure determines the power factor, though the method of line construction is an important element. Induction motors and series arc lamps tend to reduce the power factor. A purely incandescent load has a power factor of approximately unity, since there is nothing but merely the line reactance tending to lower it. On any system, the higher the frequency the lower will be the power factor, other conditions being the same. On any a. c. circuit the farther apart the wires are the greater will be the reactance, and, conversely, the closer together they are the lower will be the reactance. Line reactances are overcome by means of transpositions and placing the wires in certain positions relative to one another, which is fully explained in the chapter on transmission lines.

CHAPTER XVIII.

ALTERNATORS.—SINGLE PHASE.

Alternators do not differ in principle from d. c. machines, although they differ in details of construction, armature winding and connection, and field excitation.

Since there are two points in each a. c. cycle where the current is zero, it follows that to use an alternating current for incandescent lighting the frequency must be high enough to make the zero point of such short duration that the lamp filaments will not have time to cool appreciably, as otherwise they would "wink." Sixty cycles per second is the frequency in common use for lighting purposes, although as low a frequency as 45 cycles can be used without any noticeable winking in the lamps. A. c. motors run better on lower frequencies, although they give excellent results on 60 cycles, which is a standard frequency. The older machines have a frequency of from 125 to 133 cycles. As in a bi-polar machine the frequency equals the revolutions per minute of the loop or coil it will be seen that even as low a frequency as 60 cycles cannot be obtained with anything like a reasonable speed, as 60 revolutions per second equals $60\times60=3600$ r. p. m. Therefore, multi-polar fields are used, which enable us to get the required frequency at a comparatively low speed. In such a case a cycle will be completed during the time that a coil passes under two adjacent poles; therefore the frequency equals the number of revolutions multiplied by the number of pairs of poles. For instance, a 12-pole machine is running at 600 r. p. m.; what is the frequency?

Solution: Since the frequency equals the number of pairs of poles multiplied by the speed, we have:

$$\frac{12-\times600}{2\times\ 60}=6\times10=60$$

cycles. When the frequency per second is required and the speed is given in r. p. m. the speed per second must be found by dividing the r. p. m. by 60.

Alternator armatures differ from d. c. armatures only in being wound and connected differently. The cores are generally of the ring type and can be either drum or ring wound. The coils cannot be placed on the core the same as on a d. c. armature, however.

If a coil be wider than the space between poles it will be under two poles simultaneously for an instant every time it passes any pair of poles, and in such a case the e. m. f.'s induced in one part of coil will oppose those in the other part of the coil, until the latter has passed entirely out from under one of the poles. To obviate this the coils are made the same width as the neutral

space, that is, the distance between the poles. If, now, the poles are wider than the neutral spaces, only a comparatively small portion of the surface of the armature core can be made use of, hence the width of the poles is made equal to the neutral spaces. Figure 120 shows an armature having 8 coils and an 8-pole field.

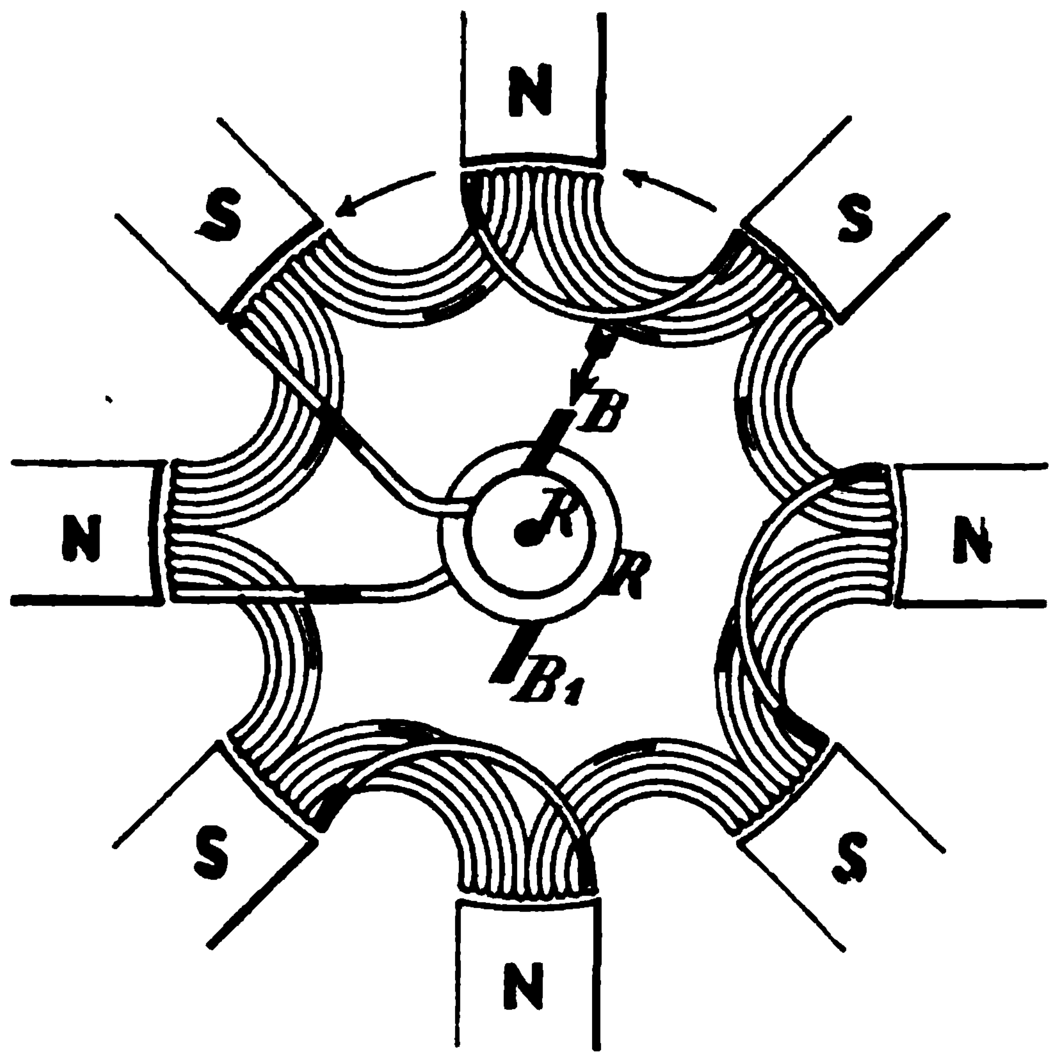


FIG. 120.

The coils are all wound alike and are connected in series, the inner end of one to the inner end of the second, outer of the second to outer end of the third and so on; like ends being connected together always. The poles being alternately N and S, it is apparent why the coils are connected in opposition, as in one coil the e. m. f.'s are acting, in say a forward direction, and in the next coil, owing to the reversed direction of cutting the lines of force, the e. m. f.'s are acting in the reverse direction; hence, if the coils were connected end of one to beginning of the next, etc., no current would flow, one-half the coils opposing the other half. They could be so connected, provided they were wound alternately right and left-hand. In the figure the direction of the e. m. f. at the instant the coils occupy the position shown as indicated by the arrows on the coils, with the rotation as shown by the arrow above the upper brush, B. The collector rings, R, are shown one within the other for sake of greater clearness. The coils are usually wound in flat rectangular shape, in such a manner that the ends project beyond the end of the core sufficiently to permit bending them down, in which position they are held by

clips or cleats of insulating material secured to the core. A machine having such an armature is called a smooth-core alternator. As will be seen by the figure, each side of a coil is half as wide as a pole, and that the space between the two sides of a coil is equal to the distance between poles. The position shown in the figure is the point where the e. m. f. is at its maximum; when the coils are between the poles they are cutting no lines of force, hence, generating no e. m. f., consequently, that is the zero position. As the armature revolves the coils come into the magnetic field gradually, that is, step by step, as each successive turn of a coil leaves the neutral space. Therefore the e. m. f. will rise gradually, being first that generated in the first turn of a coil, then the sum of the first and the second, which has now entered and begun cutting lines of force, and so on reaching its maximum when all the turns of the coils are midway under the one pole. As soon as that position is reached the e. m. f. begins to decline, as the coils are leaving the field and entering the neutral space, and will have declined to zero by the time the coils have passed entirely from under the poles. This effect is the same whether smooth or toothed cores are used, except that in the latter a curve constructed to show the rise and fall of the e. m. f. during any alternation, will have a different shape than one constructed to show the same changes for a smooth core. The former would, in all probability, be more irregular in form, which, however, would not affect the operation of the machine. Modern alternators all have toothed core armatures, that is, have their coils imbedded in slots, similar to armatures of d. c. machines. The slots are spaced apart sufficiently far to leave the iron between the two sides of a coil equal in thickness to the width of the pole. The slots are made wide enough to accommodate one-half of each of two coils. The mechanical construction differs little from that of armatures of d. c. machines, the core being also built up and mounted on a spider which is secured to the shaft by key and set screw. Insulating troughs are placed in the slots before the coils are put in to prevent electrical contact between the core and any part of the winding.

The field coils are usually connected in series and are supplied with current from an exciter, which is a small constant-potential, shunt wound, d. c. generator. It is driven by belt from a pulley on the alternator shaft, or may be mounted so that the alternator shaft also carries the armature of the exciter. Figure 121 is a diagram of the connections of an alternator; A, A, etc., are the armature coils, B, B, the brushes, C, C, the collector rings, E the exciter armature, f the exciter field, r the exciter-field rheostat, F the field of the alternator, and R the rheostat of the latter. The voltage of the machine can be regulated by means of the two field rheostats. This method is not automatic and

does not give entire satisfaction on fluctuating loads. For this reason alternators are compound-wound, similar to d. c. generators. The magnetism due to the exciter current is sufficient to generate the voltage at no load, and as load comes on the current through the series coils strengthens the field so that the machine can generate sufficient voltage to overcome the armature impedance the effect of which becomes greater as the current increases, tending to reduce the effective e. m. f. of the machine. As the polarity of the fields must be constant the current through

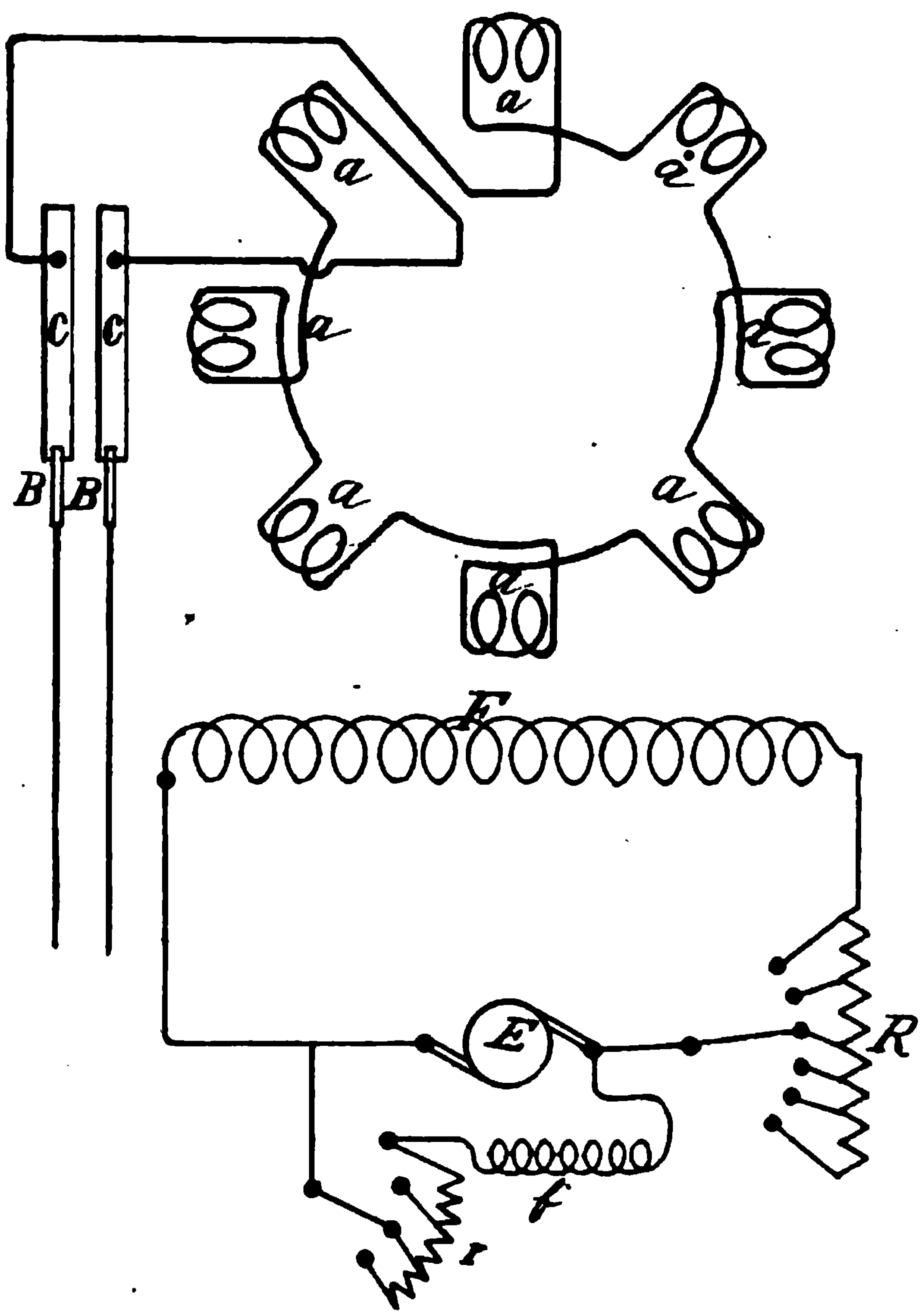


FIG. 121.

the field coils must be direct, therefore the armature current must be commuted or rectified so that its flow be un-directional. This is accomplished by means of a commutator which changes the alternating current into one whose direction is always the same in any circuit connected between the two brushes bearing on the commutator, but the current will be pulsating, that is, will rise and fall, corresponding the rise and fall of the e. m. f. during each

alternation, hence, will strengthen the field only momentarily. However, as the extra field strength is needed only as current flows, it is clear that the absence of the additional field strength when the current is zero is of no consequence, since at that instant the coils are in the neutral spaces, hence not being acted upon by the field.

Although the commutator and series coils can be inserted in the armature circuit at any point, there is an advantage in doing so at the coil midway between the ends going to the collector rings, as in that case the difference of potential between either of the main brushes and either of the rectifier brushes is only one-half the total machine voltage. When the connection is taken between one end of the armature winding and the collector ring the voltage between each of the rectifier brushes and the brush on the other collector ring equals the full machine voltage. The difference of potential between the two rectifier brushes in either case is very low, being only that caused by the drop in the series coils. Figure 122 is a diagramatic view of the connections of a Westinghouse alternator; the armature is not shown. As will be seen, the armature current does not go through the field at all, but through the primary of a small transformer, which rotates with the armature, and is connected, in series, between one of the collector rings and one end of

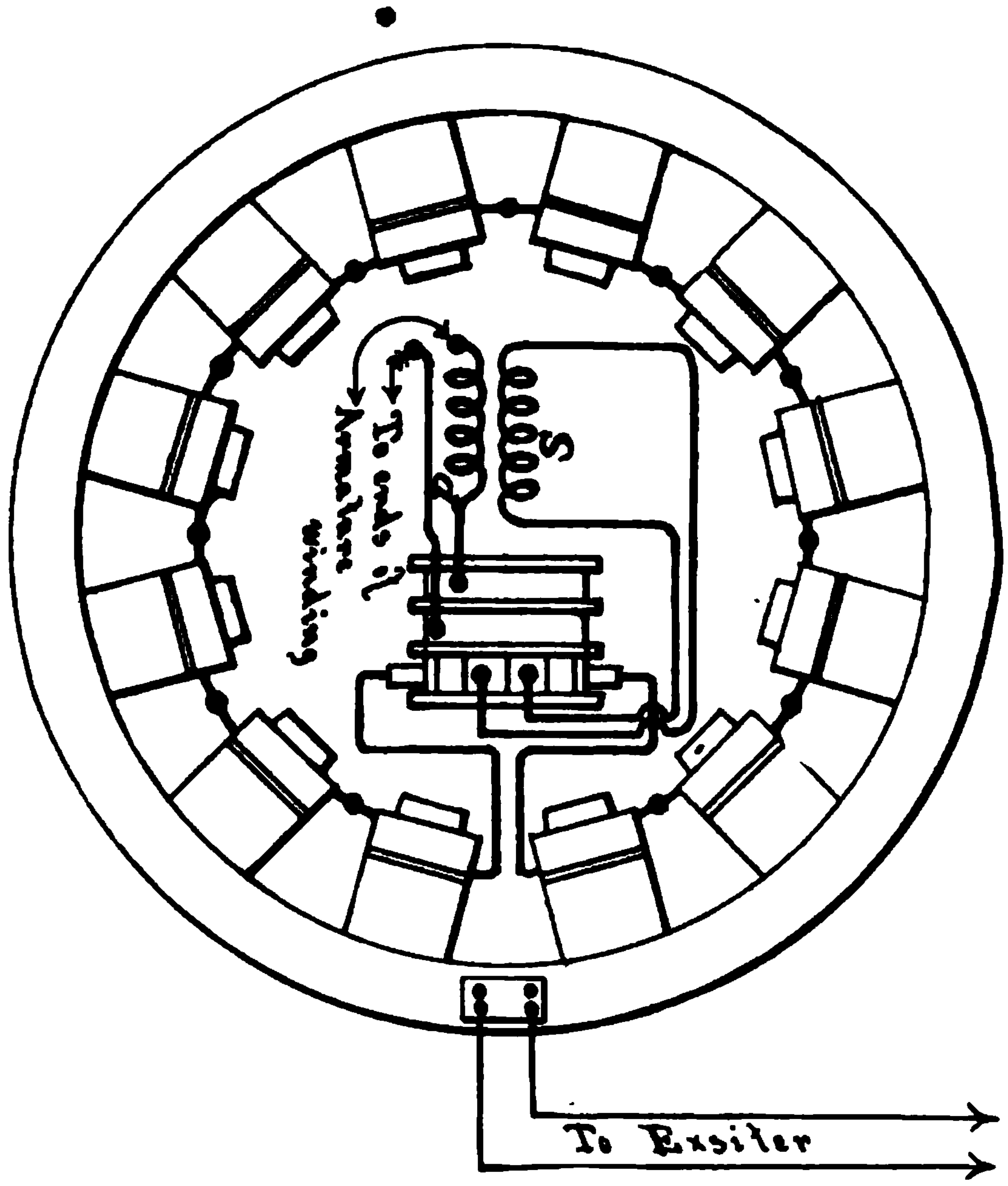


FIG. 122.

the armature winding. Therefore, no electrical connection exists between the armature and the series coils, hence the insulation of the latter is much easier, as the secondary e. m. f. of the transformer is comparatively low. The series fields as energized by the current induced in the secondary winding of this transformer, which current is always in a given proportion, practically, to the current in the primary winding; and since the latter is in series with the armature winding, and hence with the external circuit also, the current in it will vary directly as the load, thereby effecting the required change in the field strength by the variation of the value of the induced current in the secondary. In some of the smaller machines the arms of the armature spider are used for the core of the transformer.

One bad feature of the pulsating current is the sparking caused at the brushes of the commutator by the self-induction of the series coils, the self-induction opposing any change in the value of the current flowing. To obviate this, some device must be resorted to which exerts a steadying action upon the current in the series coils. The devices used are either a resistance of low self-induction, connected in shunt across the terminals of the series coils, or a small tranformer connected as explained below. The armature circuit is opened at any convenient point and the two ends are brought out and connected, each to every alternate segment of a commutator having as many segments as the alternator has poles. The series coils being connected to the brushes on the commutator, they are thereby cut in series with the armature, and, moreover, the current will be undirectional in those coils only, as a little consideration will prove. The brushes must be so set that they will touch two segments only when the e. m. f. in the coils is zero, and must be such a distance apart that they each connect to opposite sets of segments as shown; thus, if one brush is on an odd-numbered segment, the other brush must be on one of the segments having an even number.

Figure 123 is a diagramatic view of the General Electric Company's alternator, the armature also omitted. One leg of the armature circuit is connected directly to one set of commutator segments, the other end of the armature winding being connected to one of the collector rings; the other collector ring is connected to the opposite set of commutator segments to which the armature circuit is connected. Either a revolving or a stationary shunt can be used. The connections shown are for the latter; if a revolving shunt is used, its ends are connected to any two opposite commutator segments.

Alternators may be of either the revolving field or the revolving armature type or may be so constructed that both

armature and field are stationary, the number of lines of force through the coils being varied by means of an iron revolving member called the inductor. These machines are, therefore, called inductor alternators.

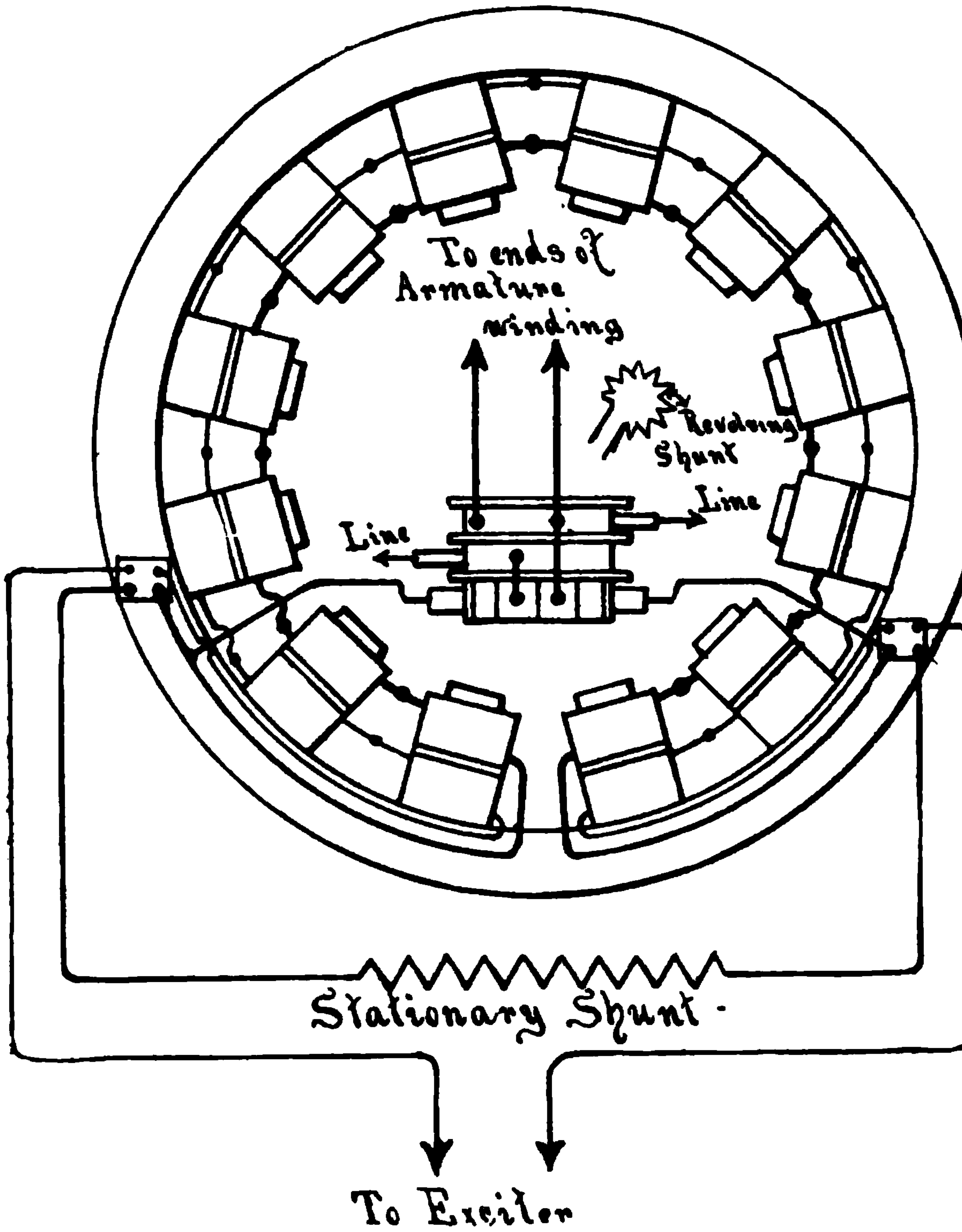


FIG. 123.

The large machines are usually of the revolving field type, in which the only sliding contacts in use are those for supplying the field with exciting current. The armature is generally on the outside of the field. Owing to the large size of armature thus obtained it is particularly well adapted to slow speeds, hence such a machine can readily be direct connected to the engine or other prime mover. Also, the armature being stationary renders its insulation a much easier matter than if it were the revolving member. Figure 124 is a cross-sectional view of a portion of one of these machines; A A, etc., are the armature coils, two being shown in cross-section; C are the field coils, the two ends, E E, going to two collector rings on the shaft. The armature core is built up of sectional sheet-iron stampings,

S, slotted on the inside for the reception of the coils; they are fastened to the cast-iron frame F by the flange B. The armature coils are held in position by wooden strips driven into the slots after the coils are in place. The poles, P, are laminated and bolted to the ring R; the field coils are held in position by the small flange, D. The ring R is bolted to the flanged end of the arms, G, which radiate from a hub on the shaft.

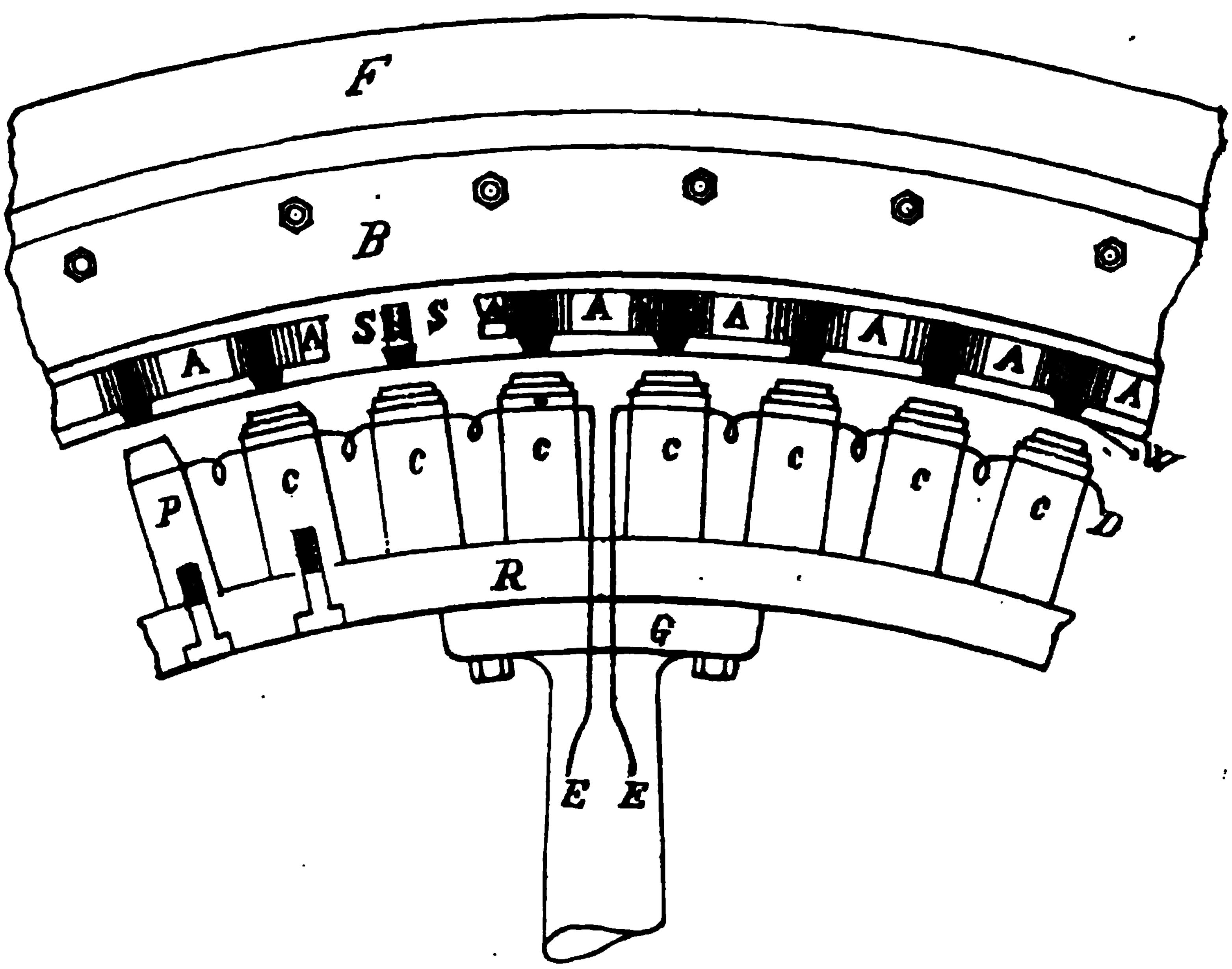


FIG. 124.

All types so far considered have but one winding on the armature and give but one current, hence, are called single-phase alternators. By the addition of one or two windings similar to the first, but each insulated from the other and having its ends connected to individual collector rings, two or three separate and distinct currents can be obtained from the same machine. Such machines are called multi-phase or poly-phase alternators, and will be considered in the following chapter.

CHAPTER XIX.

POLY-PHASE ALTERNATORS.

Two kinds of poly-phase machines are in common use, viz.: Two-phase and three-phase. The currents delivered by a two-phase machine differ in phase by 90 degrees, and those obtained from a three-phase machine differ by 120 degrees.

Since the currents from a two-phase machine differ by 90 degrees, it follows that the e. m. f. of one winding must be maximum at the instant when that of the other is zero, and in order to do so, the two sets of coils must be so placed that one set is in the position of maximum activity, that is, under the center of the poles at the instant when the coils of the other set are between the poles, hence, in the zero position. This is shown by Fig. 125. As one cycle is the distance between the centers of any two successive poles of like polarity, or twice the pitch, it is clear that the distance between the center of a coil of one set and the center of the nearest coil of the other set must equal one-fourth of a cycle, or one-half the pitch. In the figure A A, etc., are one set of coils and B B, etc., are the other set. The collector rings are shown concentric. In order to render the figure as clear as possible but four coils are shown, though their number, in practice, is considerable greater. With an arrangement as in the figure the coils need not be connected in opposition, because there being fewer coils per set, or per phase,

FIG. 125.

as it is called, the e. m. f.'s act in the same direction, as shown in the diagram, Figure 126.

The usual method of connecting up two-phase windings is by employing four collector rings, thus having two separate circuits, as shown diagramatically, in Figure 127 Another

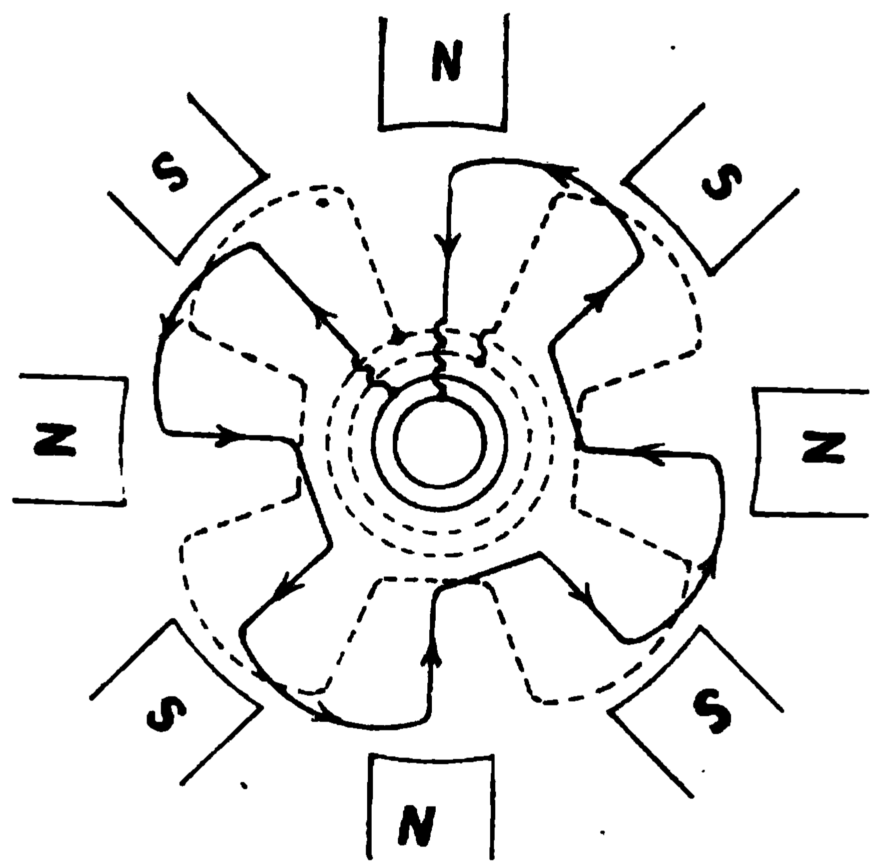


FIG. 126.

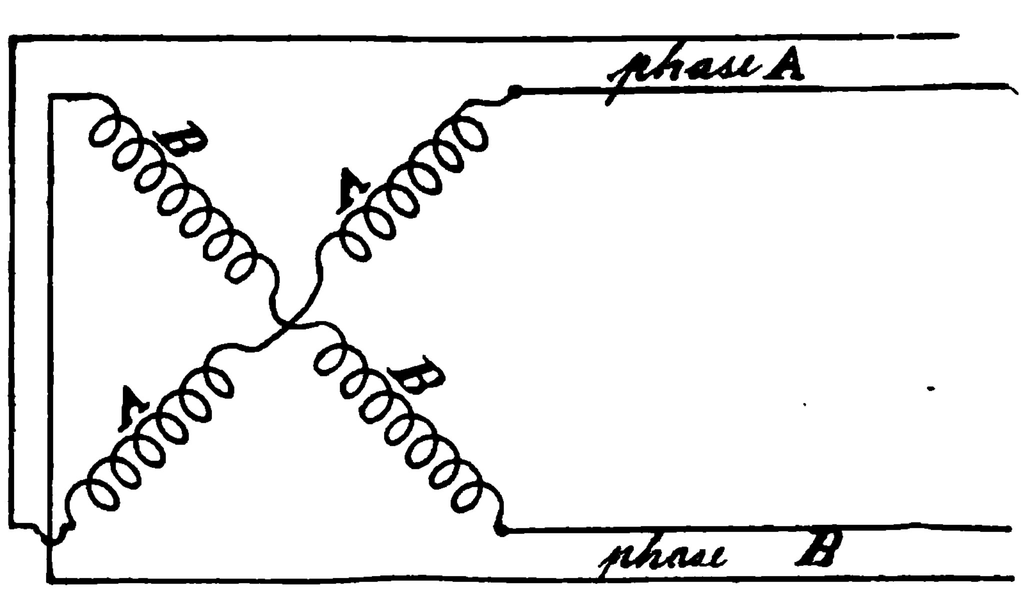


FIG. 127.

method is to connect one end of each phase to a common collector ring which thus serves as the return for both phases. Only three line wires are used, as shown by the diagram, Fig. 128. The voltage between A and B or B and C will, of course, be the machine voltage per phase; the voltage between A and C, the two outer wires, will equal the voltage of one phase times the square root of two. Thus E equals $e\sqrt{2}$ or $E=e\times1.4142$, so if the voltage of each phase equals 1000, the e. m. f. between the outside wires equals 1000×1.4142, which equals 1414.2 volts.

Also, if the current in each of the outside wires were, say 100 amperes, the current in the middle wire would be 100 $\times$ the square root of two, or $100 \times \sqrt{2} = 100 \times 1.4142 = 141.42$ amperes. The amperes per phase always equal one-half the total current output. The total current output of a machine working on a circuit whose power factor is unity (non-inductive load) equals

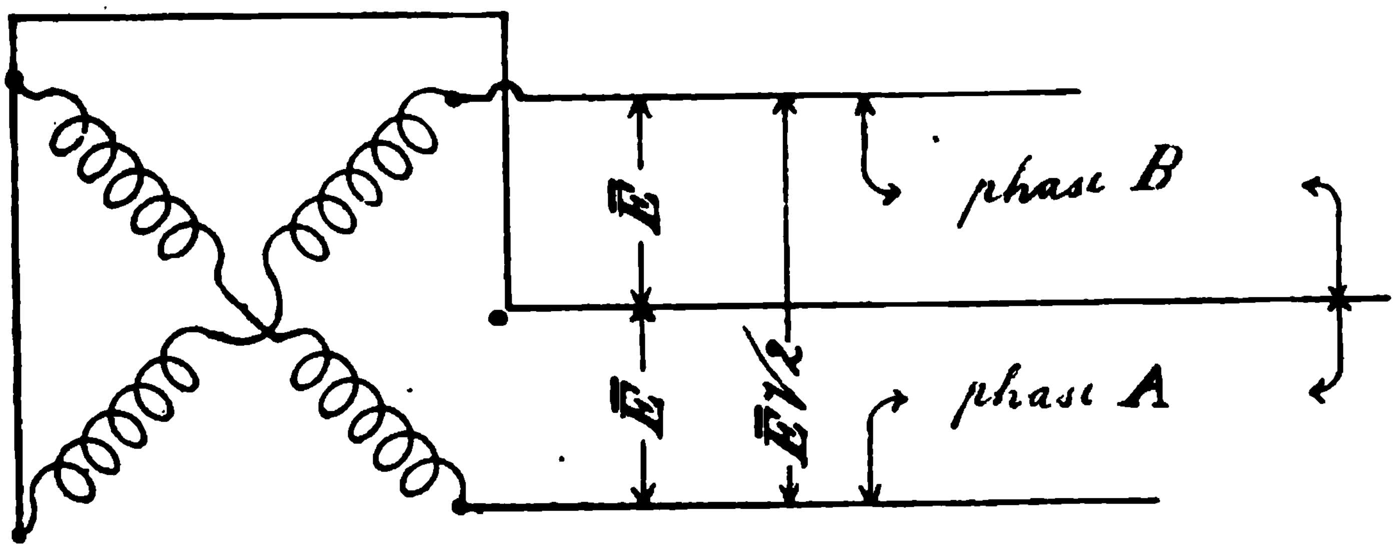


FIG. 128.

the total output in watts divided by the voltage of either phase. Where the load has a lower power factor than 1, the above result should be divided by the power factor to find the true current flowing. Thus, supposing a 100 K. W. machine at 2000 volts were on a circuit having a power factor of .80; what is the total current flowing?

Solution: Since the total current flowing equals the quotient of the watts divided by the voltage, divided by the power factor, we have:

$$\frac{\dfrac{100000}{2000}}{.80} = \frac{50}{.80} = 62.5 \text{ amperes.}$$

$$\text{The amperes per phase} = \frac{62.5}{2} = 31.25 \text{ amperes.}$$

A three-phase machine is one which will deliver three separate currents, each 120 degrees from either of the others. This necessitates placing the coils of phase A one-third the angular distance between any two successive like poles ahead of those of phase B, and those of phase C an equal distance behind those of phase B.

The e. m. f.'s of the three phases are equal, that is, the voltage generated in one set of coils at the maximum activity equals that generated in any of the other sets at the maximum activity. Figure 129 is a diagram of the windings, one set being in heavy lines, one in light lines, and the other in dotted lines;

only three collector rings are shown, no more being necessary, as will be explained presently. The two ends of each phase could be brought out each to a separate collector ring, necessitating the use of six rings and six line wires; this is shown in the diagram, Figure 130. A simpler method is shown in the diagram, Figure 131, which shows the three inner ends connected

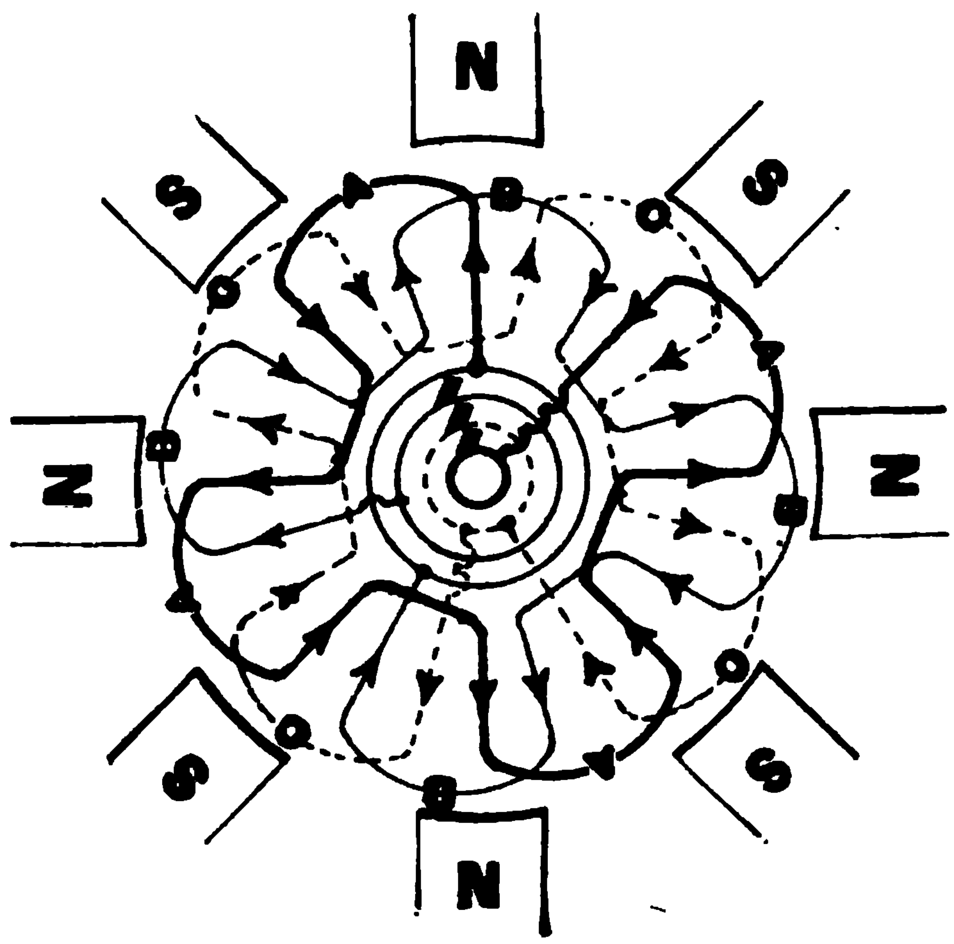


FIG. 129.

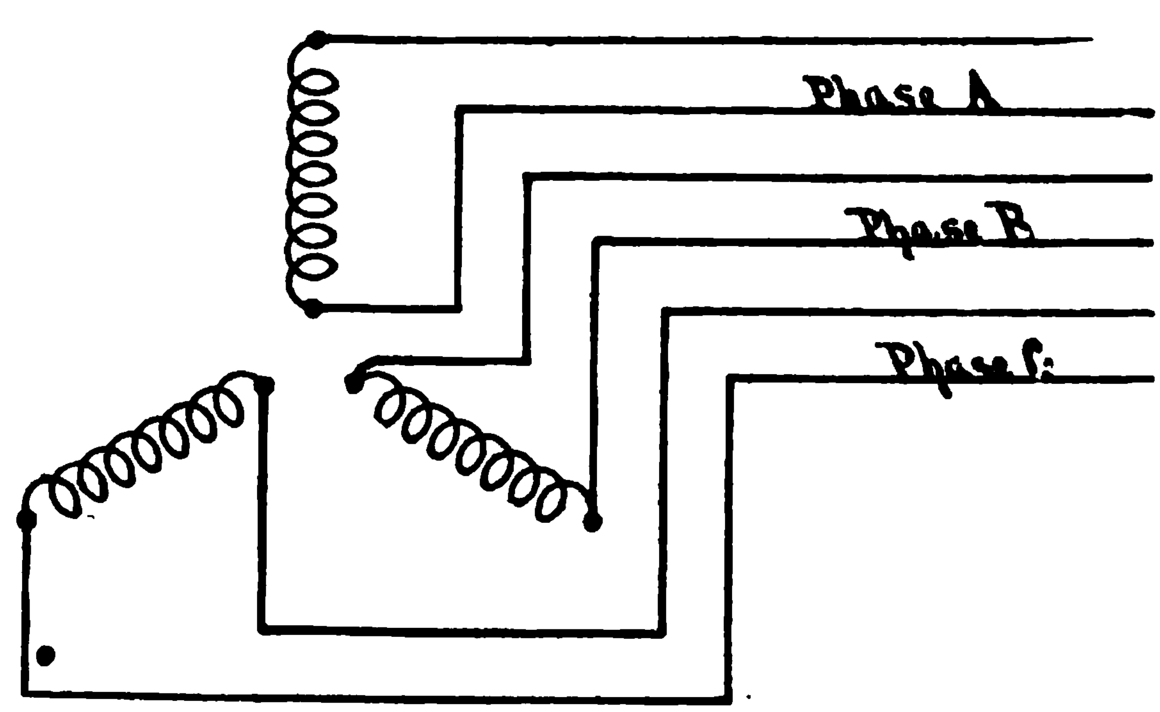


FIG. 130.

to a common ring and return wire. This reduces the number of rings and wires to four. As, at any instant, the algebraic sum of three equal currents differing in phase by 120 degrees is zero, evidently the return wire carries no current and can, therefore, be omitted. However, it is used sometimes where the different phases are likely to become unbalanced, in which case current would flow in the return wire.

Probably the most common method of connection is that shown by the diagram, Figure 129, called the "Y" or "star" connection. One end of each phase is connected to a common junction, J. The same relative end of the three sets must be connected to the common point, as can be seen by considering the direction of the flow of current in the three phases, shown by the arrowheads on the coils; the current in A at that instant

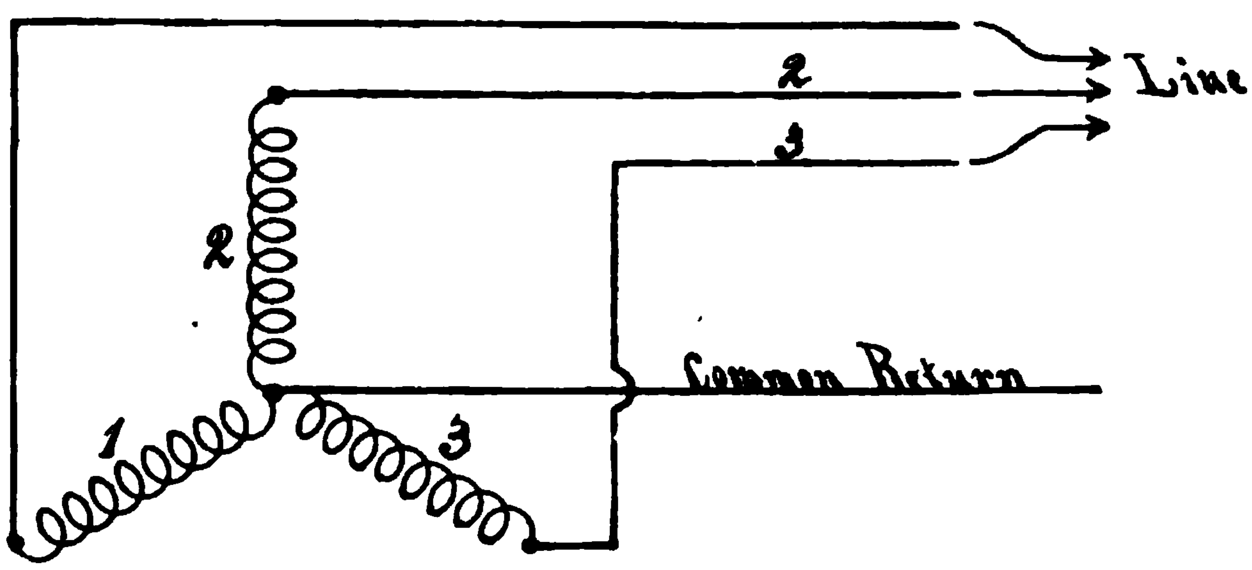


FIG. 131.

is away from J and is at maximum, that is, coils are under centers of poles. The currents in the other two sets being at the same instant each equal to one-half that in A, but opposite in direction thereto, they must flow towards J. The other ends go to the collector rings and to the line; this is shown diagrammatically in Figure 132. The three currents are obtained between

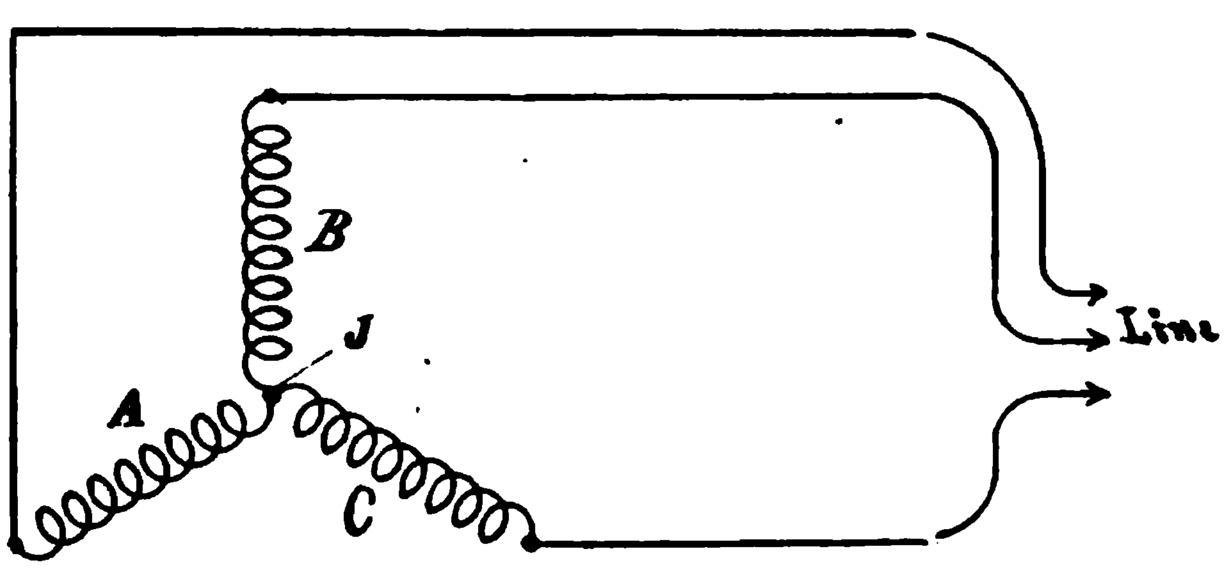
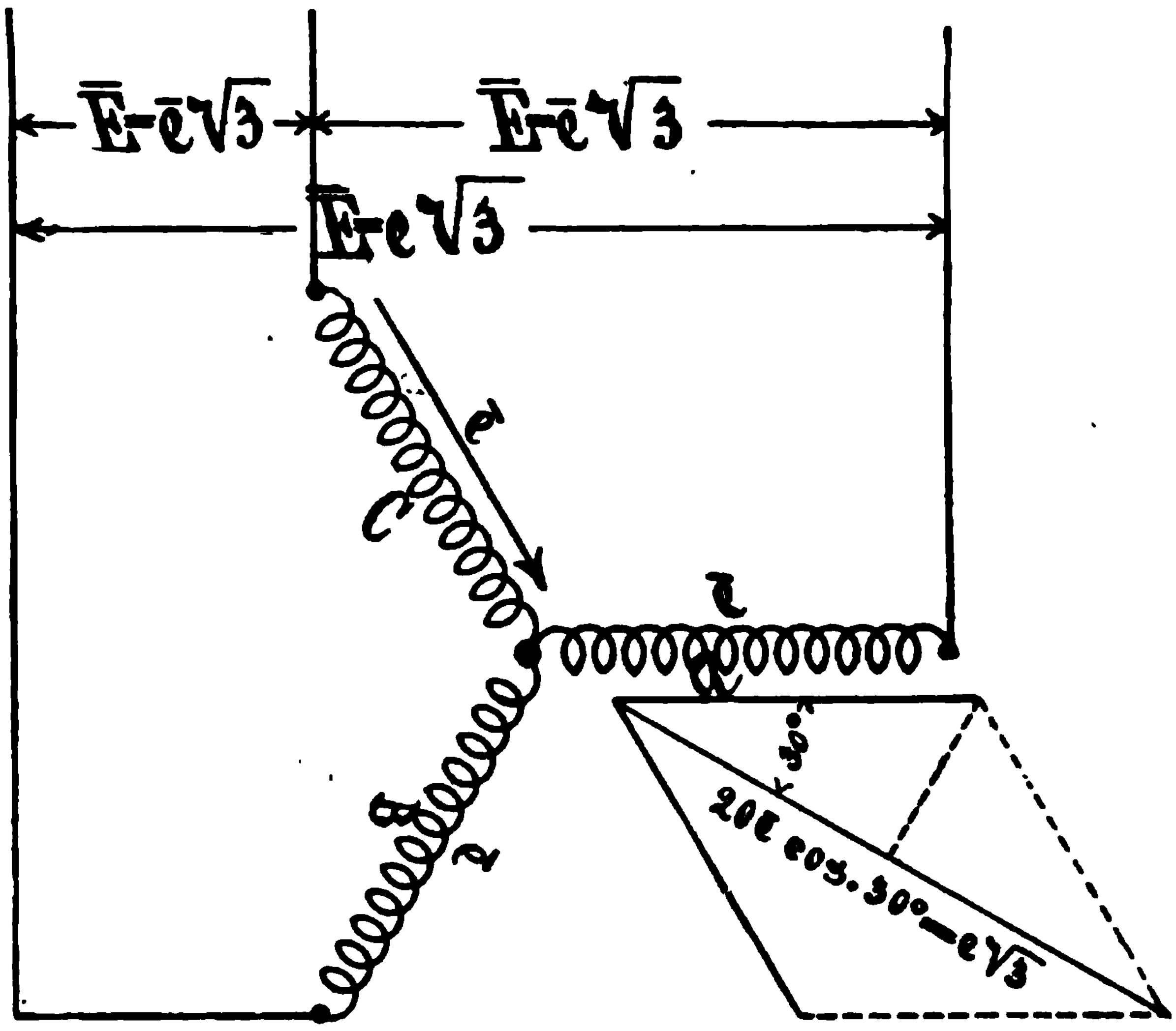


FIG. 132.

the central and each of the outer wires and between the two outer wires, as shown in the diagram, and the voltage between any two wires equals the voltage generated in one phase multiplied by the square root of three. See Figure 133. Thus, if the e. m. f. per phase = 1000 volts the e. m. f. between any two ends = $1000 \times \sqrt{3}$, or $1000 \times 1.732 = 1732$ volts. The current in the armature is the same as that in the line.

Another method of armature connection, which is also extensively used, is the "delta" (Δ) or "mesh" connection, shown in the diagram, Figure 134. The three windings are connected in series as shown, the juncture being made at the collector rings, of which there are also three. The line voltage is equal to that generated by either one of three phases; the current in each phase of the armature, however, equals the current in the line, divided by the square root three; thus, if the line current is 100 amperes, the current per phase will be:

$$\frac{100}{\sqrt{3}} \text{ or } \frac{100}{1.732} = 57.74 \text{ amperes.}$$ See Figure 135.



Diag. of Y connected 3 phase Arm.

FIG. 133.

The output in watts is the same whether the armature be Y or delta connected; in either a delta or a Y connected machine the output on non-inductive load =1.732 × current per phase × voltage per phase. The difference between the two is that the Y connection will give a higher line voltage than that generated per phase, hence is more suitable for high potential work than a delta connected machine; the latter connection is better adapted to larger current output, as the armature windings need not be made large enough to carry the entire line current. The current per phase in either case, however, if the machine is operating on

an inductive load will equal the current on non-inductive load divided by the power factor, thus:

$$\text{Actual current} = \frac{\text{current on non-inductive load}}{\text{power factor}}$$

The foregoing figures also hold good for the phases of alternating current motors.

Poly-phase currents are used principally on long distance transmission lines and for the operation of induction motors, although lights can be operated thereby also. In which case, however, single-phase secondary distribution is employed. On motor loads the frequency is usually lower than on lighting loads, in some cases being as low as 25 cycles. The reason for the use of the lower frequency is that (motors being an inductive load and, therefore, having a fractional power factor) the lower the frequency the nearer unity the power factor will be, on any given load.

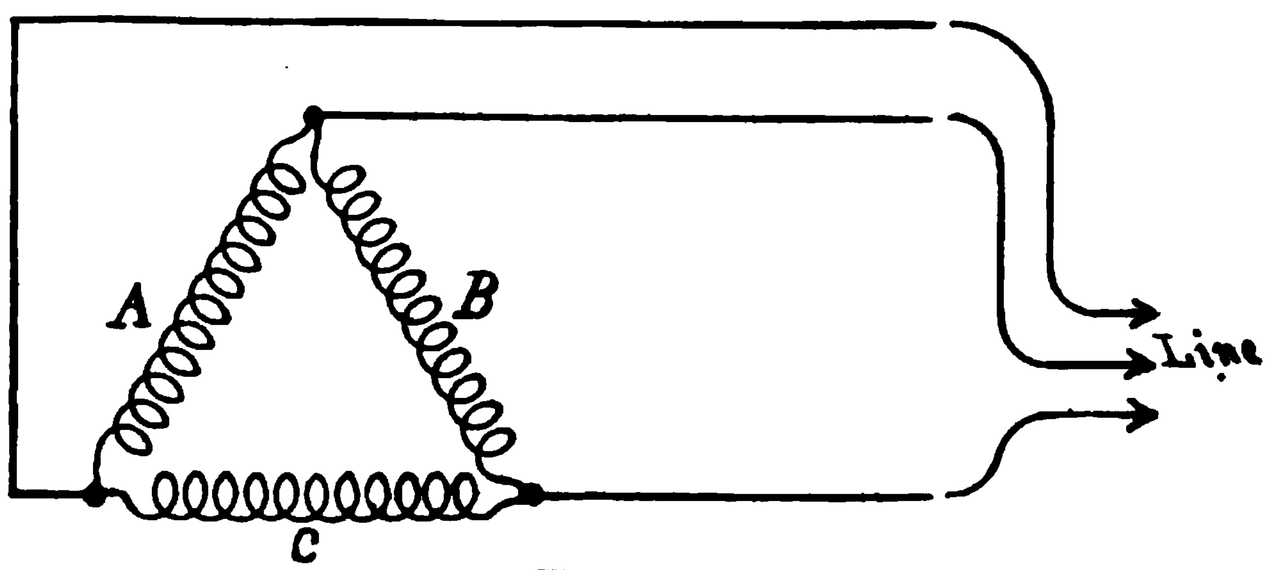
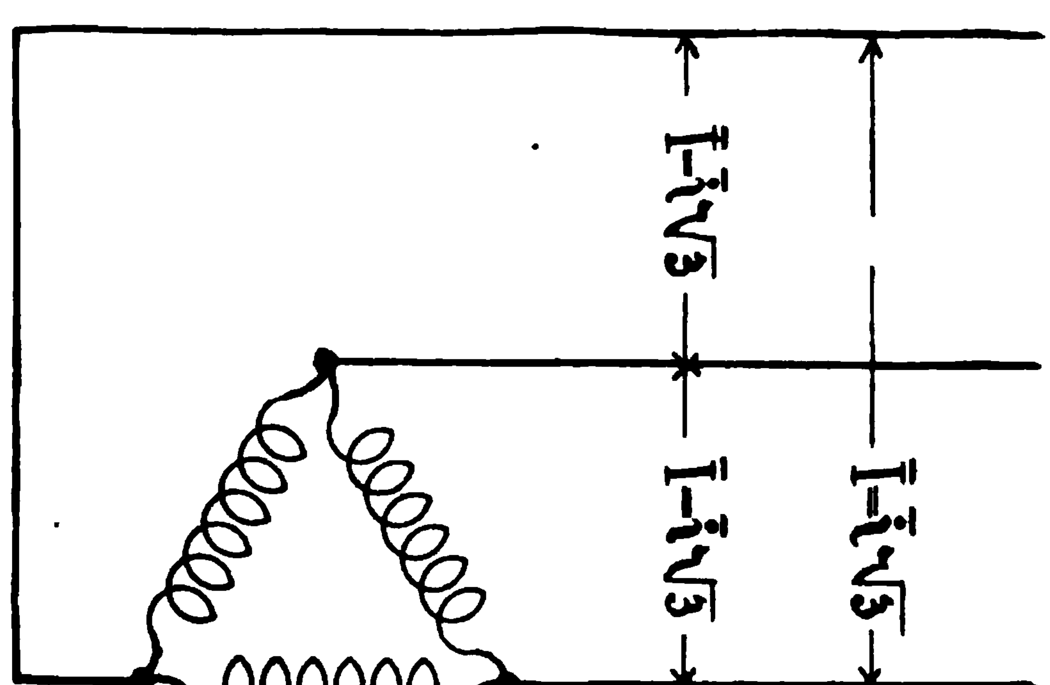


FIG. 134.



Diag. Delta connected 3 phase Arm.

FIG. 135.

The monocyclic alternator is, one might say, a cross between a single-phase and a poly-phase machine. It is practically a single phaser, having one main winding, the ends of which are connected to two collector rings. A second winding of one-fourth the number of turns is placed 90 degrees behind the main winding. This small winding is called the "teazer" and one end is connected to the main winding half way between the ends of the latter, the remaining end going to a collector ring mounted on the shaft between the two main collector rings. The e. m. f. of the teazer will therefore be 90 degrees out of phase with the e. m. f. of the main winding and will be one-fourth as great. The e. m. f. between the middle and either outside wire will equal the square root of the sum of the squares of one-half the main voltage and the teazer voltage (which latter is one-fourth of the main), hence, if the main voltage is 2000, the voltage between teazer and either outside wire is:

$$\sqrt{\left(\frac{2000}{2}\right)^2+\left(\frac{2000}{4}\right)^2}$$

$$\sqrt{1000^2 + 500^2} =$$

$$\sqrt{1000000 + 250000} =$$

$$\sqrt{1250000} = 1118 \text{ volts.}$$

This type of machine was designed for stations where the larger part of the load consists of lights, but where it was desired to operate motors from the same machine; the motor load being only a small percentage of the total load. The lighting load is connected directly across the outer wires, the teazer, or power wire, being run only to where a motor is installed. The connections are shown in the diagram, Figure 136. The object

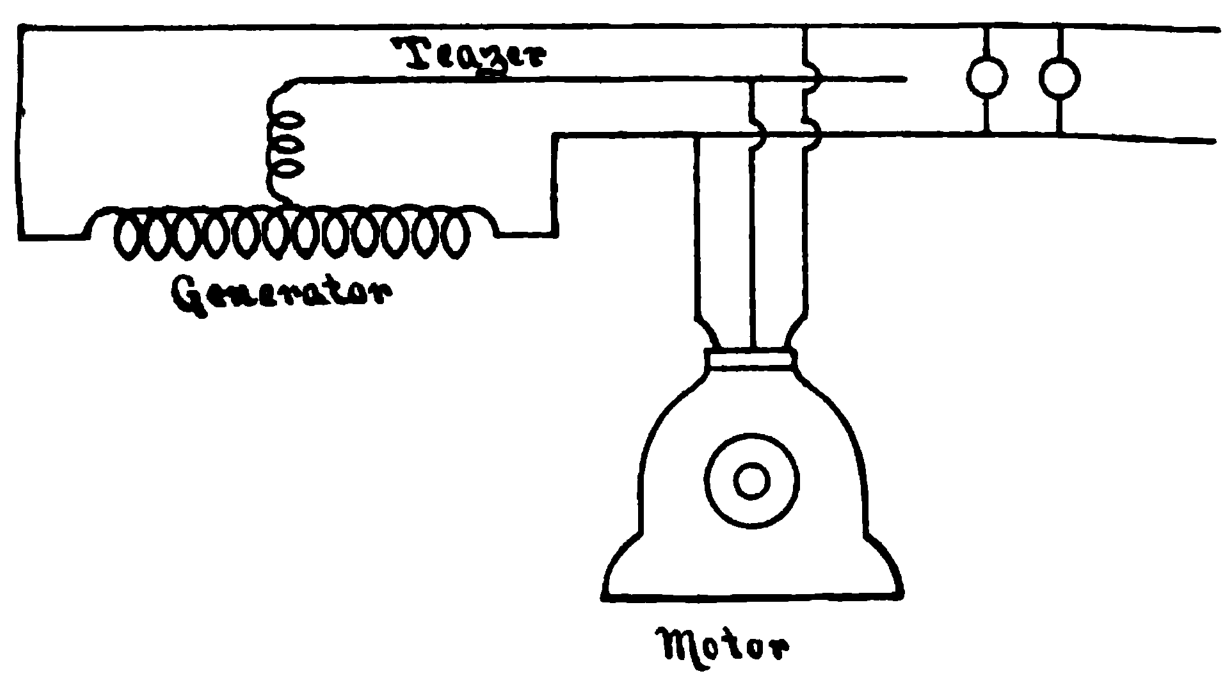


FIG. 136.

of the teazer winding is to furnish motors with an out-of-phase starting current, as at the time that this system was brought out single-phase a. c. motors were not made self-starting, that is, they could not start themselves from rest, but required to be brought up to speed by some auxiliary device. Today self-starting a. c. motors can be purchased up to 30 h.-p. capacity, which give very good results. The monocyclic system has not come into very extended use, the number of monocyclic plants installed in the United States being comparatively few.

CHAPTER XX.

TRANSFORMERS.

Transformers are used to change either the form of electric currents or their pressure; or it may be that both change of form and change of pressure is obtained at the same time. They are divided into two general classes, viz: Static and rotary transformers.

A static transformer consists essentially of a laminated iron core and two windings or sets of windings, which latter are carefully insulated from one another and from the core. It contains no moving parts of any kind, and is used to change the voltage of an a. c. circuit, or to change the phase relation of two or more alternating currents, as will be explained later on. It can not be used at all in connection with direct currents. The two windings differ from one another inasmuch as one consists of a great many turns of small wire, as compared to the other, which latter has less turns, but of heavier wire. They are called the primary and secondary windings, and either the coarse or the fine winding may be the primary or secondary. That winding which is connected to the circuit whose voltage is to be transformed is called the primary, while that from which the transformed voltage is obtained is called the secondary. The number of turns on the primary is always in a certain ratio to the number of turns on the secondary. This is called the ratio of transformation and thereupon depends the value of the secondary voltage, with any given primary voltage. Thus, a transformer having a ratio of ten to one (10:1) will give a secondary voltage of one-tenth that of the primary circuit if the fine winding is used as the primary. If the coarse winding were used as the primary the secondary voltage would be ten times that of the primary circuit. Such a transformer would have ten times as many turns on the fine winding that it has on the heavier one. A transformer can be used to either raise or lower the voltage; in the former case it is called a step-up, and in the latter case a step-down transformer. Any change of voltage, however, is

always accompanied by a corresponding change in the available current. That is to say, if the ratio of transformation of a 10 K. W. transformer is 20:1, and current is supplied to it at 2000 volts it would take $\frac{10 \times 1000}{2000} = \frac{10000}{2000} = 5$ amperes of current; since the ratio of transformation is 20:1, the secondary voltage will be $\frac{2000}{20} = 100$ volts, and 10 K. W. at 100 volts equals $\frac{10000}{100} = 100$ amperes, which is the current that can be obtained from the secondary. From this it follows that the secondary voltage always equals the primary voltage divided by the ratio of transformation, and the secondary amperes equal the primary amperes multiplied by the ratio of transformation. Dividing the number of turns on the primary by the number of turns on the secondary gives the ratio of transformation.

Although, theoretically, the energy in the secondary equals that in the primary, nevertheless the full amount is never available, owing to some unavoidable losses in the transformer. These

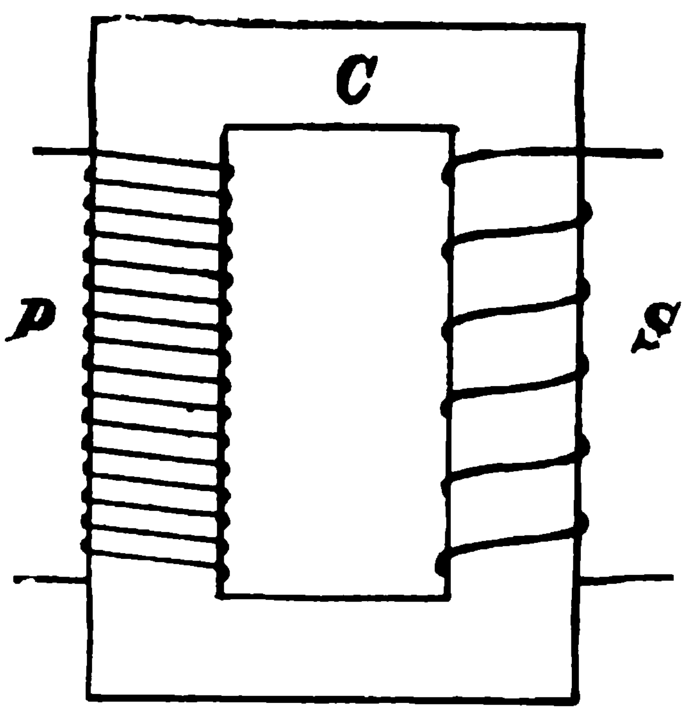


FIG. 137.

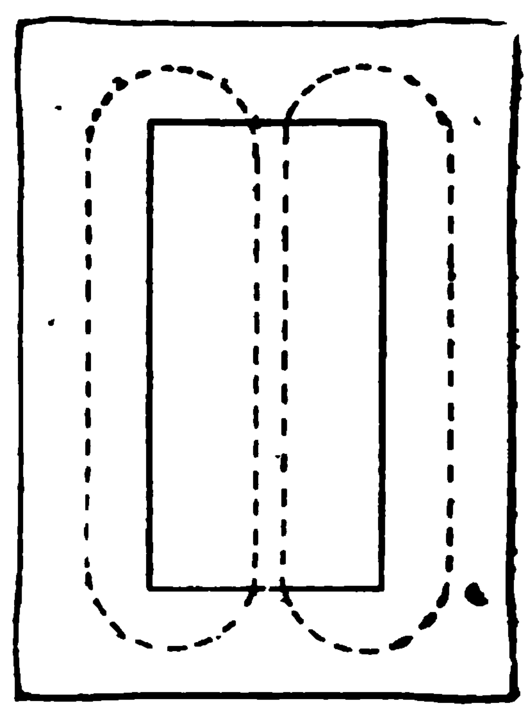


FIG. 138.

losses are very small, however, even such small transformers as three K. W. having an efficiency of over 96 per cent., while some very large ones recently built have an efficiency of nearly 99 per cent. As in all apparatus, the efficiency $= \frac{\text{watts output}}{\text{watts intake}}$.

The core is built up of thin sheet iron stampings, precisely like an armature core, and for the same reason. It is made to form a closed magnetic circuit, and upon this core the coils are placed. Figure 137 shows a simple transformer in which C is the core, P the primary winding, and S the secondary. As soon as the primary winding is connected to an a. c. circuit a current will flow through it, setting up an alternating magnetic flux in the core. Now as the turns of the secondary winding also embrace this flux an e. m. f. will be set up therein, which, when the secondary circuit is closed, will cause a current to flow. The primary coil has high self-induction, hence very little current will flow through it as long as the secondary is open. As soon, however, as the secondary is closed, a current will flow therein, and this current will set up an alternating magnetic flux which is in opposition to that set up by the current in the primary coil, thereby lowering the self-induction of the primary, thus permitting a stronger current to flow in the latter. As the increase of current in the primary is directly proportional to the current flowing in the secondary it is clear that a transformer is self-regulating.

The transformer shown in Figure 137 would not be very efficient on account of its great magnetic leakage. Since the flux set up by the secondary current is opposed to that produced by the current in the primary, the tendency is to produce consequent poles at the portions of the core between the two coils, in which case there would be a leakage of magnetic lines from one end to the other, as shown in Figure 138. Hence, the secondary coil would not get the full benefit of the magnetizing effect of the primary. And as the leakage would be greater the heavier the load on the secondary, there would be a greater reduction in the secondary voltage as the load increased, causing what is called poor regulation. The regulation of a transformer is the difference between the secondary voltage at no load and that at full load, usually expressed in per cent of the former. Nearly all of this leakage is gotten rid of by a proper placing of the coils and construction of the core. There are two types of static transformers, relative to method of construction, viz: The core type and the shell type. Figure 139 represents the core type. The core is built in rectangular shape. The coils are placed on the side pieces as shown, the primary being wound over the secondary. By this means all of the lines of force must thread through both coils, hence leakage is practically eliminated. The sheets forming the sides are all of equal length but are assembled so that one end of a sheet overlaps an end of its neighbor a distance equal to the width of the end pieces, as shown in Figure 140. This leaves a number of interstices at each end which are necessary for the reception of the end pieces. The latter are driven in

after the coils are wound on, the coils not being wound long enough to prevent the ends from being driven in their entire width. When a sufficient number of sheets for one side are assembled they are clamped together, insulated, chucked in a lathe and the secondary winding is put on. The primary is wound on over this, being, of course, well insulated from the secondary. Two such coils and cores are assembled by driving end pieces of suitable dimensions into the interstices between the laminæ of the cores. The entire structure is then placed in an iron case. Flexible leads connected to the ends of the coils are brought out through holes

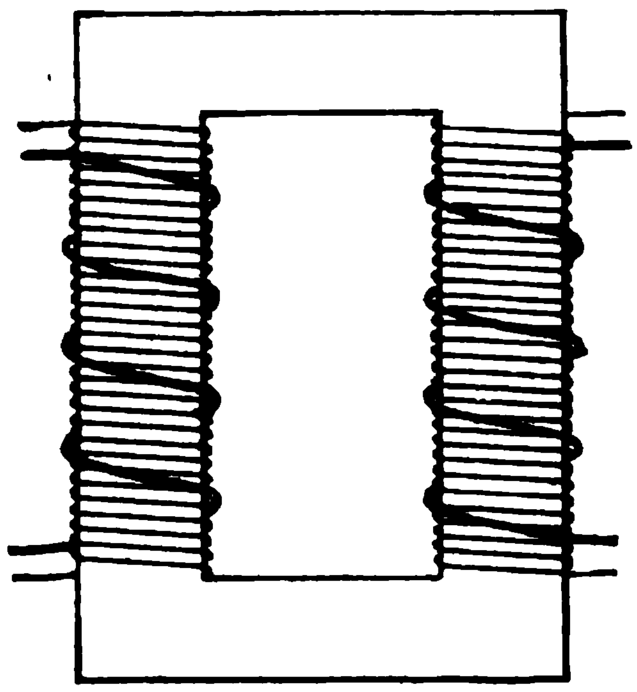


FIG. 139.

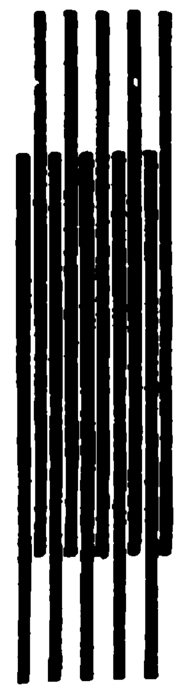


FIG. 140.

in the side and near the top of the case, insulating bushings of porcelain being used to prevent contact between any of the wires and the case where the wires come out of the latter.

Shell type transformers have their coils wound on a form by machine. After being wound and insulated they are ready to be placed on the core, or rather have the core placed on them. There are usually two primary and two secondary coils, the latter two being placed side by side, the primary coils being placed one on each side of the secondaries. The core is built up of sheet-iron stampings of a form shown in Figure 141. These sheets are cut at the line C, thus permitting the middle piece to be bent out. Each sheet is slipped on over the coils, the middle piece being bent out sufficiently to let the sheet be slipped on readily. When the latter is in place the middle piece is bent down and the next sheet put on. The sheets are generally put on so that the joints are broken, that is, come alternately on the right and left-hand side. Coils and core fully assembled and ready to be placed in the case are shown in Figure 142.

It is very essential that the coils fit the core tightly in each type of transformer, so that none of the coils or wires can move. This is necessary to prevent vibration of the coils, which would

sooner or later destroy the insulation. Owing to the fact that the currents flowing in them are alternating the coils are subjected to racking stresses, the dynamic action due to the flow of current tending to move the coils first in one direction and then in the other. These reversals taking place many times a second the bad effect of even a very small amount of movement or play can be readily imagined. Such a rapid vibration would soon reduce the best of insulation to fragments, resulting in burning out the transformer.

The losses in a transformer are the iron or core loss and the copper—or, as it is sometimes called, the I^2R loss. The core loss is the energy that is consumed for magnetizing the core. As the

FIG. 141.

FIG. 142.

core is being magnetized and demagnetized many times a second it is very plain that there must be a loss due to hysteresis, because the reversal of magnetism is slower than the current reversals. As the amount of hysteretic loss depends upon the quality of the iron, with any given frequency and magnetic

density, it is at once apparent that a good quality of soft iron is essential to an efficient transformer. This loss goes on all the time that the primary current is on, regardless of whether any current is flowing in the secondary. It is, therefore, generally kept lower than the copper loss, as the latter varies with the load.

The copper, or I^2R loss, is the energy lost in overcoming the resistance of the coils, some of the voltage being consumed to force the current through this resistance. As this loss does not go on except when the transformer is loaded it is not of such great consequence as the core loss. The greatest objection thereto is its effect on the regulation. Since the heavier the load the greater the copper loss, it follows that just at the time that the loss in the wiring is maximum, the available voltage is lower than it should be; also, since at heavy loads the primary current is maximum a greater portion of the primary voltage is needed to overcome the resistance of the primary coils, thus reducing the voltage available for overcoming the self-induction of the latter, hence further reducing the secondary e. m. f. and further impairing the regulation. In comparing the relative efficiency of transformers the all-day efficiency should be considered rather than the maximum efficiency, especially if they are to be used where the primary circuit is always alive, and the load, or the greater portion thereof, is on only a few hours, the remaining portion of the twenty-four only a few, or perhaps no lights at all, being used. In such a case a transformer having a high all-day efficiency should be used even though its maximum efficiency may be lower than that of another one, which latter has, however, low all-day efficiency. The maximum efficiency is obtained when the secondary is worked at its best point, generally full load, during the entire time that the current is flowing in the primary. Since the cases where such a condition exists obtain only in exceptional instances, it will be readily understood why the average or all-day efficiency will always be lower than the maximum, because one portion of the loss (the core loss) will be just as great at light loads as it is on full loads. Take the case of two 3 K. W. transformers, one having a core loss of seventy-five watts and a copper loss of fifty watts, the other having a core loss of sixty watts and a copper loss of ninety-five watts. The maximum efficiency of the first is:

$$\frac{3000}{3000 \times 75 \times 50} = \frac{3000}{3125} = 96\%,$$

that of the second would be:

$$\frac{3000}{3000 \times 60 \times 95} = \frac{3000}{3155} = 95\%.$$

If conditions are such that the transformer can be operated at full load or nearly so during the entire time that the primary

circuit is alive the first transformer should be installed, as its efficiency is 96 per cent. against 95 per cent. of the second. But supposing that the primary circuit is alive day and night, but the load is on but four hours each day, being nil the remaining twenty hours; let us see if the first transformer would be the proper one. Its core loss being seventy-five watts there is a consumption of $75 \times 24 = 1800$ watts per day for core loss; since the copper loss is fifty watts, but only takes place while load is on, viz.: four hours, we have $4 \times 50 = 200$ watts; total $1800 + 200 = 2000$ watts loss. Energy obtained from transformer=3000 watts for four hours equals 12000 watts; total energy consumed by transformer = 12000 watts + 2000 watts; iron and copper loss equals $12000 + 2000 = 14000$ watts. The average or all-day efficiency is, therefore, $\frac{12000}{14000} = 85.7\%$.

The second transformer has a core loss of sixty watts, therefore $60 \times 24 = 1440$ watts copper loss, ninety-five watts for four hours equals $95 \times 4 = 380$ watts; total losses $1440 + 330 = 1820$ watts. Energy delivered by transformer equals 3000 watts for four hours $= 3000 \times 4 = 12000$ watts; energy consumed by transformer $= 12000 + 1820 = 13820$ watts. Hence, all-day efficiency $= \frac{12000}{13820} = 87\%$ (nearly). Therefore, the second transformer, although having a lower maximum efficiency than the other, is the more economical one under such a condition, since its all-day efficiency is greater; other things being equal it should be given preference.

Transformers generate considerable heat when in use. No difficulty is experienced, however, in getting rid of this heat by radiation, without resorting to any artificial means of cooling, in the sizes up to 40 or even 50 K. W., especially as these sizes and smaller are usually placed on poles, hence get the benefit of any breeze that may be stirring. The larger sizes are usually cooled either by air blast or have oil-filled cases, the oil serving to conduct the heat from the coils to the case. Some of the latest transformers of large size are oil filled and have a system of pipes placed in the case, a flow of cold water being maintained in the pipes to carry off the heat.

Oil is seldom used in transformers of fifty K. W. capacity or smaller, though its use is strongly recommended by some electrical engineers and construction men. The author does not advocate the use of oil in any transformer up to fifty K. W., and the reason is this:

"As already stated, these sizes are usually placed on poles and are therefore generally exposed to the sun all day, or the greater part thereof. The sun will generate considerable heat in the iron case; the oil will transmit this heat to the coils just as readily as it will convey the heat generated in the coils to the case. Then in the evening, when the load comes on, the coils will be as hot as they would very likely be after a run of several hours at full load, whereas, in the absence of the oil, the air space between the coils and the case would have prevented any great absorption of heat by the former, hence the coils would be much the cooler at the time the load was put on, and would very likely be cooler at the end of the run than an oil filled transformer would be at the start, other conditions being the same."

Some dry transformers have an opening on the bottom and one or two in the sides near the top, the latter being equipped with shields so that falling water can not possibly enter. As soon as the coils begin warming up the air in the case is thereby rendered less dense than the atmosphere, hence air will enter through the bottom hole. As the heated air has a tendency to rise some of it is forced out of the opening at the top, being replaced by cool air entering from below, which in turn rises as it is heated by contact with the coils. Thus a circulation of air is established which prevents an excessive rise in temperature of the coils.

Core type and shell type transformers each have their respective advantages and disadvantages. As the leading authorities on the subject are divided in their opinion the arguments used by the representatives or champions of the two types are given.

Advantages of the shell type transformers (by a manufacturer of the shell type): "There being only one joint in the magnetic circuit of the core of our transformer its reluctance is lower than that of the core type, which has four joints in its magnetic circuit, hence it takes less energy to magnetize it, therefore its core loss is lower, resulting in a higher all-day and also higher maximum efficiency. The coils being form-wound, are wound very close and tight, resulting in an entire absence of vibration of any of the wires and by firmly assembling the various coils there can be no vibration of any coil. We can insulate the coils much better in this method of construction than is possible in the core type.

"The construction of our core and the disposition of the coils eliminates leakage entirely, another reason why the efficiency is greater.

"As our core loss is low we obtain the maximum result with a minimum amount of wire, hence, the I^2R loss is lower than that

of the core type, which means, besides higher efficiency on this account, also a much better, in fact, almost perfect regulation.

"As our losses are lower, our transformer does not heat near so much as a core type, under similar conditions. Disadvantages, None."

Advantages of the core type transformer (by a manufacturer of the core type): "The presence of the four joints in the core of our transformers gives it a distinct advantage over the shell type. It may seem, that owing to the higher reluctance of the core, due to the four joints, our core loss would be greater, requiring a greater magnetizing current. Just the reverse is true, however.

The greater reluctance results in considerably reducing the residual magnetism that the core will retain. As this residual magnetism must be overcome at each reversal of the current it follows that the less there is of it, the less energy will have to be expended in overcoming it. Therefore, our core loss must necessarily be less than that of a shell type. Our method of construction also permits us to compress the core to a greater extent thus preventing vibration. The coils being tightly wound on the core or on spools which fit the cores tightly, there is no chance for any coil or wire to vibrate. The ventilation is better than it can possibly be in a shell type. This is due to the fact, that as our cores are square in cross-section, or nearly so, while the coils are circular, there are four open spaces between each core and coil, and, as the coils are in a perpendicular position (axially) in the transformer case, there is a circulation of air on the inside of the coils as well as on the outside, while in the shell type the circulation can affect the outside of the coils only, and but a small portion thereof at that, the coils of the latter being surrounded almost entirely by iron. Winding the primary and secondary coils one over the other assures an entire absence of magnetic leakage and also permits of more insulation between the two, especially as winding space is not so much restricted as it is in the shell type.

As our hysteretic loss is lower it follows that less excitation is needed, which means less wire in the primary, and as there is no loss of magnetic lines less wire is needed in the secondary. Hence the $I^2 R$ loss, as well as the core loss will be lower than in the shell type, resulting in higher all-day as well as maximum efficiency. The regulation is very close, in fact, almost perfect, owing to the low copper loss. The losses being low, there will be very little heating, and what little heat there is generated is very easily gotten rid of by the superior ventilation of our transformer. Disadvantages: None."

The efficiency of transformers is very much impaired by what is known as "ageing" of the iron in the cores. Ageing of iron is

a gradual deterioration that takes place in it when continually subjected to the magnetizing effect of alternating currents. Until comparatively recently this phenomenon and its effects were not considered, in fact, was not known to exist. The result of this ageing is that the core loss becomes much greater, owing to the fact that the iron is more difficult to magnetize. This effect can be almost entirely avoided by use of the highest grade of iron possible to obtain. The ageing process is very slow, in fact, hardly noticeable, in the best grades of iron.

The insulation used in transformers should be of the best. Mica is largely used for this purpose, on account of its ability to resist heat as well as its insulating quality and its hardness. Most transformers for lighting purposes have two primary and two secondary coils, and both ends of each secondary coil are brought out through the case. This is done to make the ratio of transformation as well as the secondary voltage interchangeable, by a proper connection of the coils.

Transformer coils can be connected either in series or in parallel, just as other electrical appliances, and the method of connecting has the same effect on the voltage and current in all cases. Two or more transformers can also be connected together in series or parallel (or banked as it is called) as well as the individual coils of one. But whether connecting together two coils or two transformers, it is important to get the connections right, relative to polarity. Do not start to work with the impression that because a transformer is used with alternating currents polarity can be ignored. True, neither leg of an a. c. circuit can really be called positive or negative, yet at each and every instant one leg must be either positive or negative, relative to the other, and the same is true of the terminals of transformers or their coils. A wrong connection of either the primary or secondary coils will result either in burning out the coils or in not getting any current from the secondary. To prevent mistakes and confusion every transformer manufacturer sends out a diagram of connections with every transformer, showing the methods of connecting for the various voltages. Each transformer also bears a name plate giving its capacity and both primary and secondary voltage. Moreover, the same method of connecting applies to each and every transformer, large or small, in any given make, that is, the leads are all brought out in the same relative manner in each transformer. Most transformers are equipped with a porcelain terminal block inside the case, the ends of the primary coils being connected each to a terminal thereon. By suitably connecting the different terminals together the series or parallel connection can be effected, as for instance, if the transformer is marked 1000 or 2000 volts primary the coils should

be connected in series on a 2000 volt primary circuit, and in multiple when used on a 1000 volt circuit. Figure 143 shows a diagramatic view of such a terminal block. A being the series and B

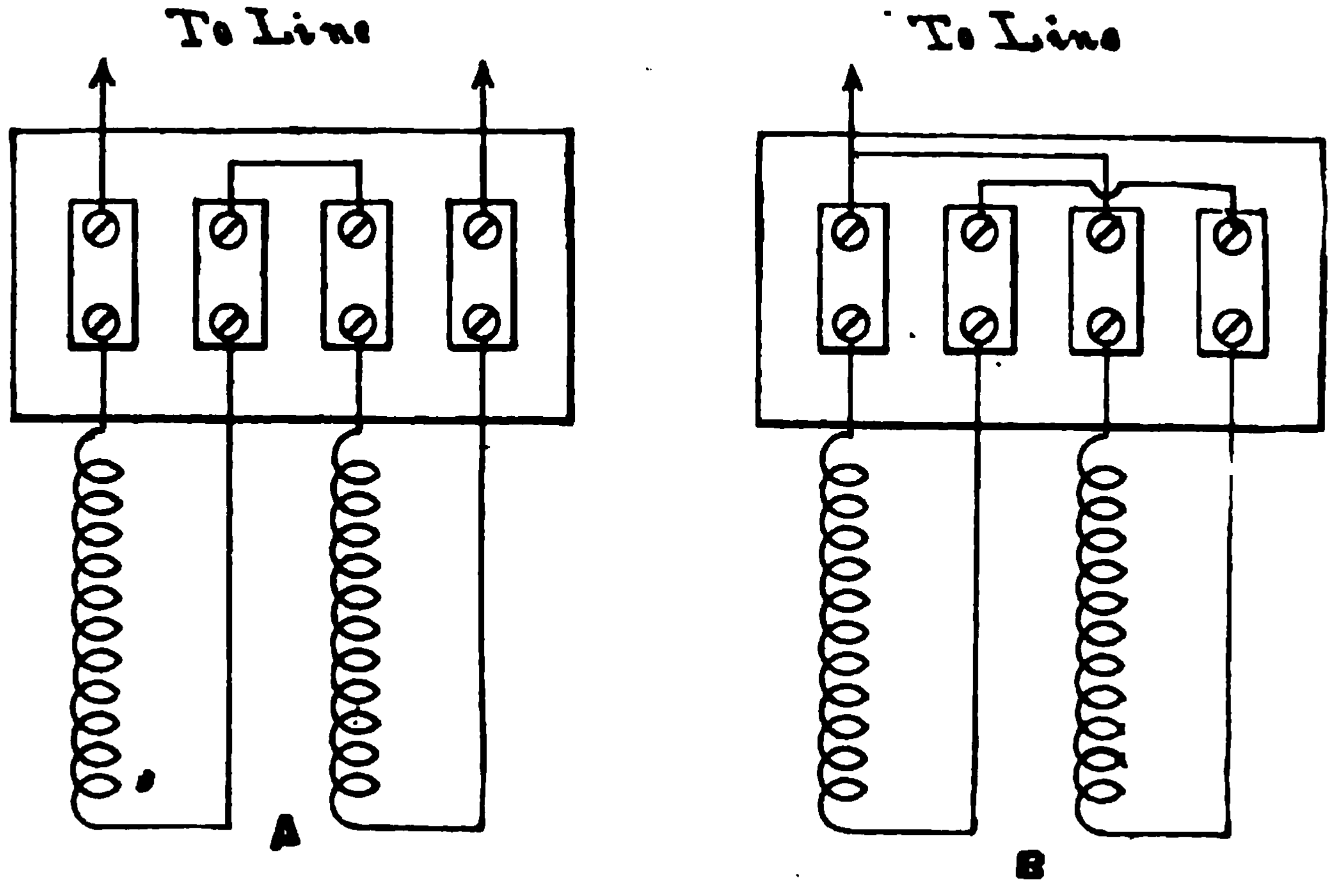


FIG. 143.

the parallel connection. By this means only two primary leads need be brought out through the case. Four secondary leads are generally brought out and their relative position is the same in practically all the different makes of transformers, so that the same method of connecting that applies to one applies to all, as a rule, which is shown in Figure 144. However, in connecting up a strange transformer, it is well to take a good look at the manufacturer's diagram, or in the absence of such, to make a test to see which two ends belong to one coil. This can be done

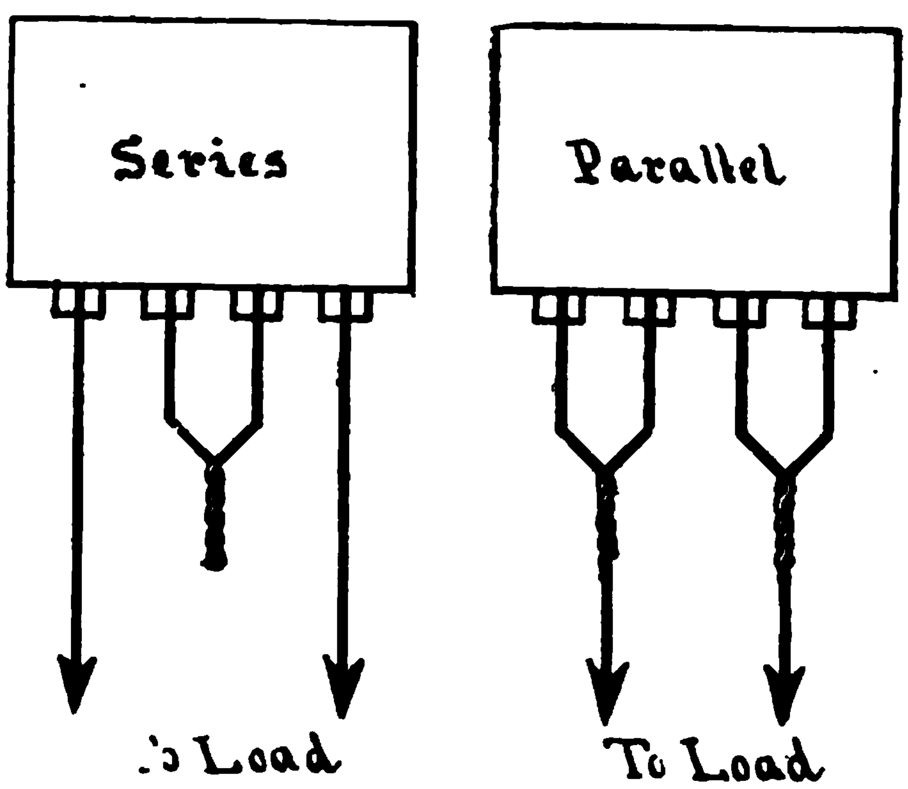


FIG. 144.

easily if the primary is alive and an incandescent lamp is at hand, by connecting one side of the lamp to one of the secondary leads and the other side thereof to each of the other secondaries until the one is found which belongs to the coil whose other end is connected to the lamp, in which case the lamp will burn. Having determined the two ends of one coil the ends of the other will of course also be known, there being but four in all. In case the primary circuit is dead, test out the coils with a magneto or an ordinary vibrating bell and battery. It is not sufficient, however, to know the ends of the coils; one must also make a polarity test; that is, to ascertain which ends of the two coils have the same polarity. The same test must also be made when connecting together two transformers of different makes.

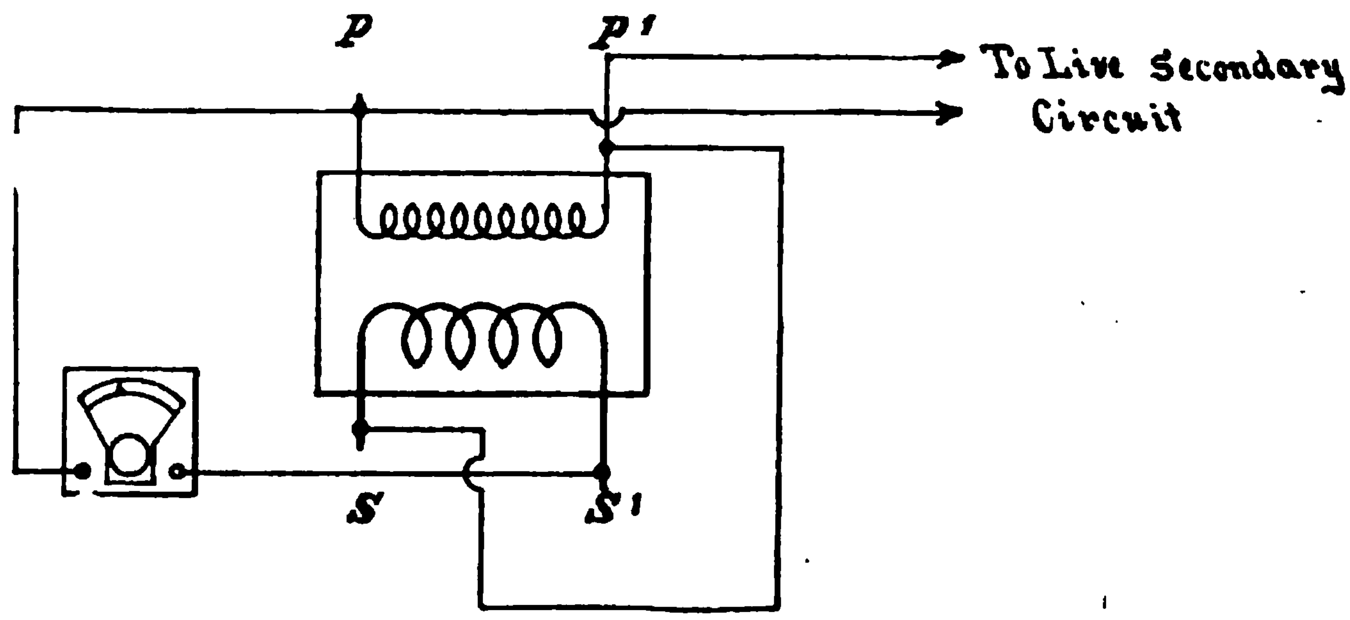


FIG. 145.

This test is made as follows: Figure 145 shows a diagramatic view of a transformer, P and P¹ representing the primaries, S and S¹ the secondaries. Connect P¹ and S together and connect P and P¹ to a secondary circuit that is alive. Now measure the voltage between P and S¹; if it is greater than the voltage applied to the primaries, the secondary lead S and the primary lead P have the same polarity, that is, at the instant that the current flows into the primary through P and out of the secondary through S.

If the voltage between P and S¹ is less than that applied it shows that the leads P and S¹ are of opposite polarity. Another method is to connect the primaries of the two transformers to be used together in parallel and their secondaries also in parallel, placing a small fuse in series with the latter. Connect the primaries to a primary circuit. If the relative polarity of the two transformers is the same the fuse will remain intact, whereas if they have opposite polarity the fuse will melt, since in that case the secondary of one would be short circuited by the secondary of the other. Therefore the fuse should be small enough to

prevent injury to the transformer; it must be large enough, however, to carry what is known as the exchange current, which is a light current that always flows in the secondaries when connected as described. This exchange current should never be greater than 1 per cent. of the full load current. When two transformers are to be connected in series it is essential that their carrying capacity in amperes be the same and when two transformers are to be connected in parallel it is essential that their ratio of transformation be the same, as otherwise one of them would be likely to be burned out.

Transformers can also be used to feed a three-wire distributing system by having the two coils of the secondary connected in series, the two ends that are connected together being also connected to the neutral, and the remaining two ends each being connected to one of the outside wires of the system. Two separate transformers can also be used in the same way. However, while all transformers will work satisfactorily on a three-wire system as long as the two sides are not much unbalanced, and some of them will work fairly well even on poorly balanced loads, it is nevertheless advisable to use transformers having regular three-wire secondaries for three-wire systems.

The difficulty with the ordinary transformer on unbalanced load is due to the greater copper loss in the coils feeding the heavier load side of the system, which causes the voltage of the latter to fall below that of the lighter loaded side. This is obviated in the transformers built for three-wire service or having what is termed three-wire secondaries. All transformers should have both primary and secondary fuses. The latter are placed in a suitable fuse-box on the pole, or in a readily accessible place near the transformer, where the latter is not on a pole, and the secondary fuses are within a short distance from where the secondaries enter the building where current is to be used. Always use as near as possible the right size fuse wire; it is cheaper to replace a blown fuse than a burned-out transformer. To find the size fuse for the primary or secondary windings divide the capacity of the transformer in watts by the primary voltage to find the primary amperes, and the capacity by the secondary voltage to find the secondary amperes. Always feed as many consumers from one transformer as you conveniently can, as there is a distinct advantage in using larger sizes, owing to their higher efficiency as compared to the smaller ones. Outlying residence lighting, of course, frequently necessitates the use of an individual transformer for one consumer. Where a number of consumers are near together, especially if they take considerable current, they can be most economically fed by a three-wire system, placing one transformer with three-wire secondaries at or near each

end of the feeders, or place a single one as near as possible to the center of the load. Work them as near full load as safety and conditions will permit, because the nearer full load you work them the higher an efficiency you will get out of them, be they large or small.

Static transformers are also used in connection with a. c. measuring and recording instruments. A. c. voltmeters are not, as a rule, connected directly across the two legs of a high-potential circuit whose voltage is to be measured, as is done with d. c. voltmeters. A small pressure transformer is used instead, the primary winding being connected to the circuit whose voltage is to be measured and the secondary to the voltmeter.

Since the ratio of transformation is constant, the secondary voltage must always be in a certain proportion to that of the primary. The voltmeter, therefore, will always indicate the value of the primary voltage. A. c. ammeters of large capacity are usually equipped with what is termed a series transformer, instead of a shunt as d. c. ammeters. The primary of this series transformer consists of one or two turns of sufficient cross-section to carry the entire current, and is connected in series with one leg of the circuit. The secondary also has but few turns, of small wire.

As all the line current is used to magnetize the core of this series transformer it is evident that as the line current varies, the ammeter must at once show the variation, since the secondary e. m. f. and hence the current flowing through the ammeter, is always proportional to the magnetizing effect of the primary. When such instruments are used care should be taken to see that the instrument and the transformer each bear the same number, as an instrument calibrated correctly with one transformer would very likely be inaccurate when used with another one. These transformers are equipped with flexible secondary leads of considerable length. Do not cut these off in case they are longer than is necessary to reach the instrument, as that would render the reading of the latter inaccurate. If you must lengthen them use as large a wire as practicable, so as not to appreciably increase the resistance.

Wattmeters for use on high-potential circuits are also equipped with a pressure transformer, to furnish a low pressure for the voltage coil. Some also have a series transformer for the series coils. A switch is generally provided by means of which the secondary of a series transformer can be short-circuited (except on those used with recording instruments) this switch being closed except when a reading is to be taken. When the secondary is short-circuited the self induction of the primary is thereby almost entirely eliminated, hence very little energy is lost. The

effect is very nearly the same as if no core were present. The secondary winding is, of course, heavy enough to carry the current safely. As the secondary and primary each have but few turns the current in the former cannot be very great, even on short circuit. The reason for the use of the pressure transformers is that the high voltage would be dangerous and difficult to handle and measure. A voltmeter built to stand a high voltage would necessarily be bulky, and much more likely to burn out than one built for and used on a low voltage circuit.

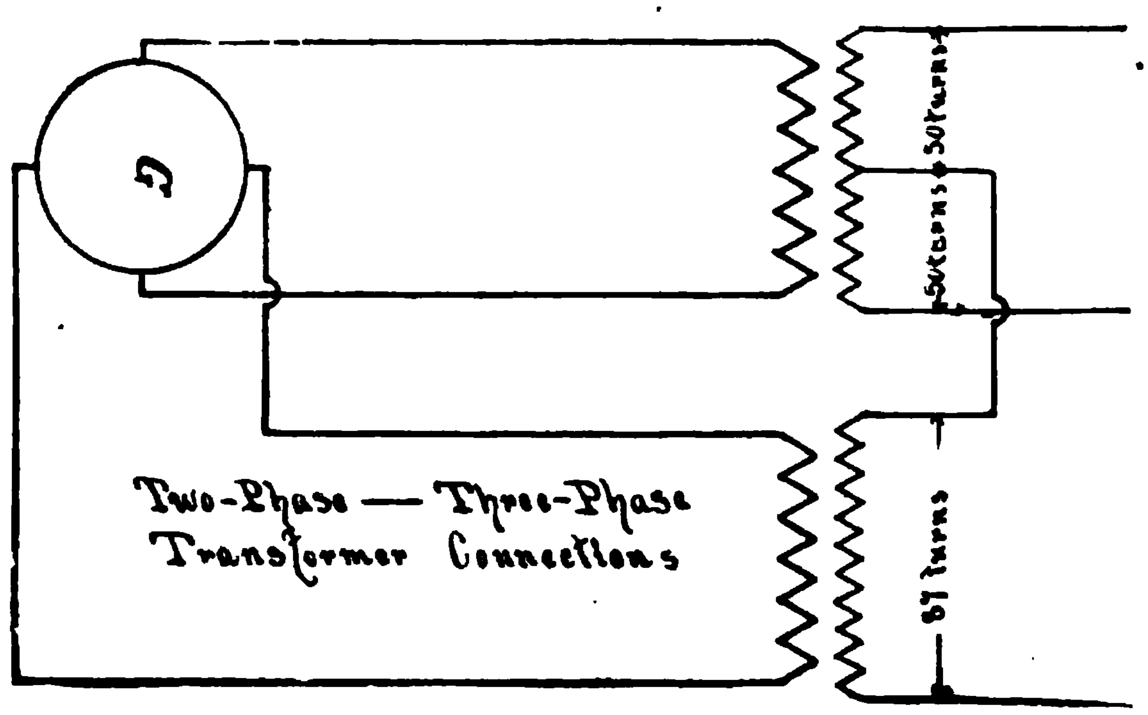


FIG. 146.

Static transformers are also used for changing the phase relation between two or more alternating currents. Figure 146 shows the method of connection for changing two phase to three

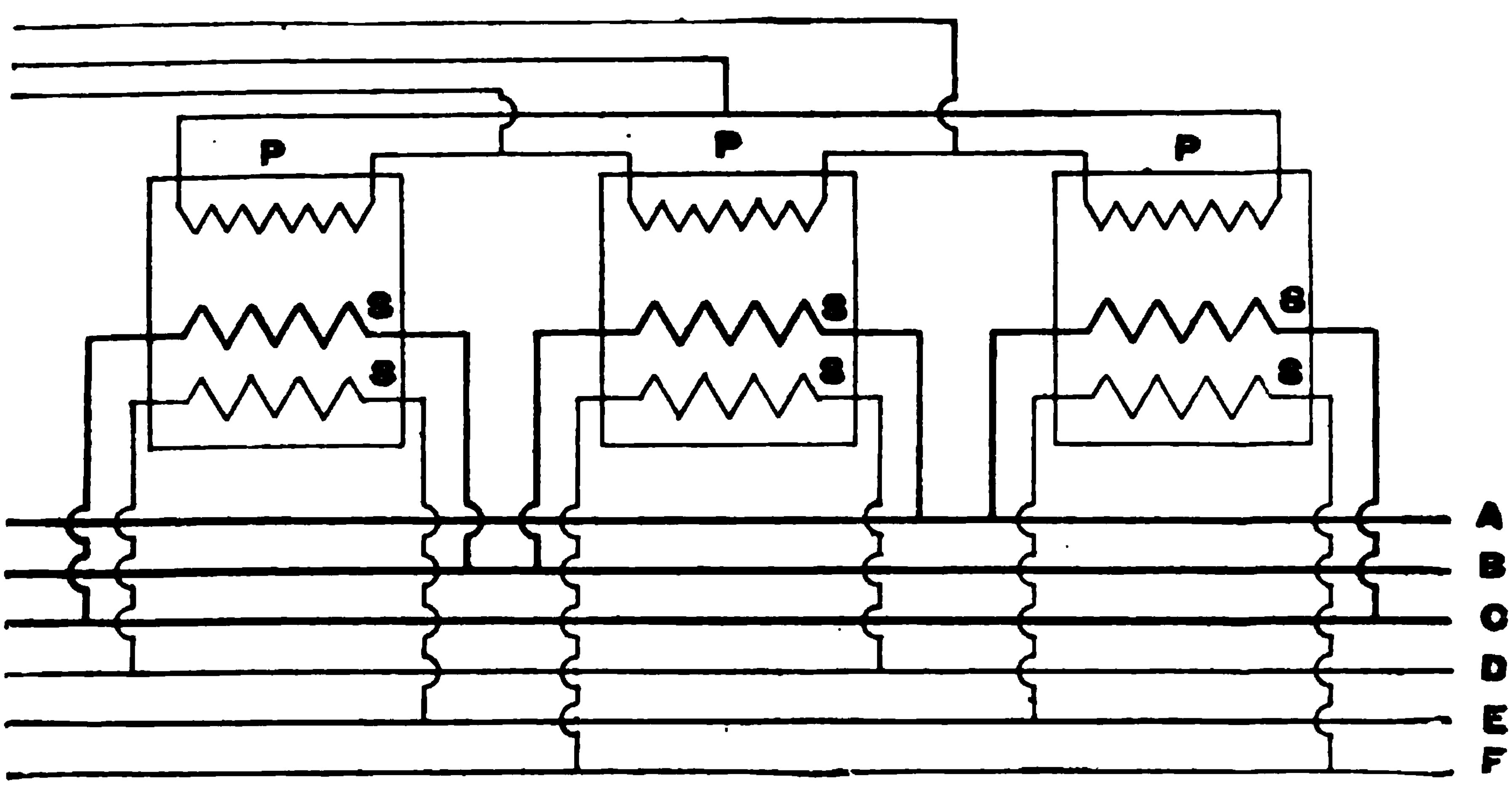


FIG. 147.

phase and vice versa and Figure 147 shows the connections for changing three phase to six phase.

Rotary transformers greatly resemble d. c. generators. If the armature of a bi-polar d. c. generator or motor be equipped with a pair of collector rings and the winding be tapped out at two diametrically opposite points and connected thereto the machine would, if driven by any external source, deliver single-phase alternating currents through the collector rings and continuous currents through the commutator. The maximum alternating e. m. f. would occur when the coils to which the collector rings are connected pass under the brushes and the effective value will be .707 of the d. c. voltage. If the machine were supplied with continuous current of proper voltage it would run as an ordinary d. c. motor and would deliver single-phase alternating currents through the collector rings whose effective value would also be

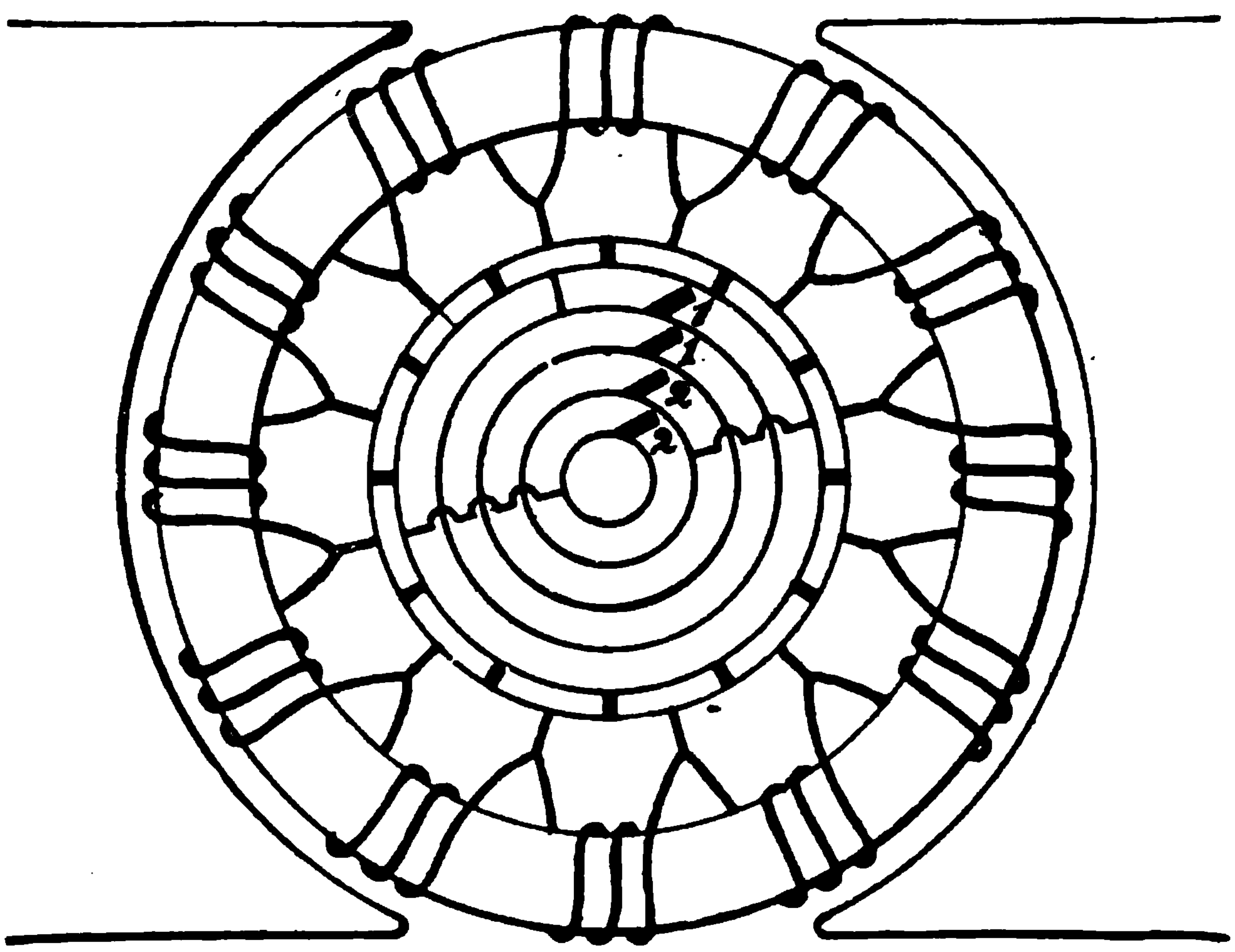


FIG. 148.

.707 of the d. c. voltage. By using four rings instead of two, each connected to the winding at a convenient point, the four connections being made 90 degrees apart, however, as shown in Figure 148, the machine would become a two-phase converter. The effective voltage of either phase would be one-half the d. c. voltage. By using three rings and connecting them to three equidistant points on the armature, Figure 149, we obtain a three-phase converter. The effective value of the e. m. f. between any two rings would be .612 of the d. c. voltage.

Practically all converters are multi-polar, however. That necessitates tapping the armature winding out to each ring as

many times as the machine has pairs of poles, the taps being at equi-distant points. Were this not done only a portion of the winding would be utilized.

When such a machine is driven by some external source of power it is called a double-current generator. The current flowing the armature always equals the sum of the currents delivered by the a. c. and d. c. end. The size of such a machine is limited by the size of a d. c. generator that can be built with the same number of poles as a good alternator. Its total output will be the same as that of a d. c. machine of the same size.

Besides being used to transform continuous into alternating currents, being in that case driven as a d. c motor, a converter

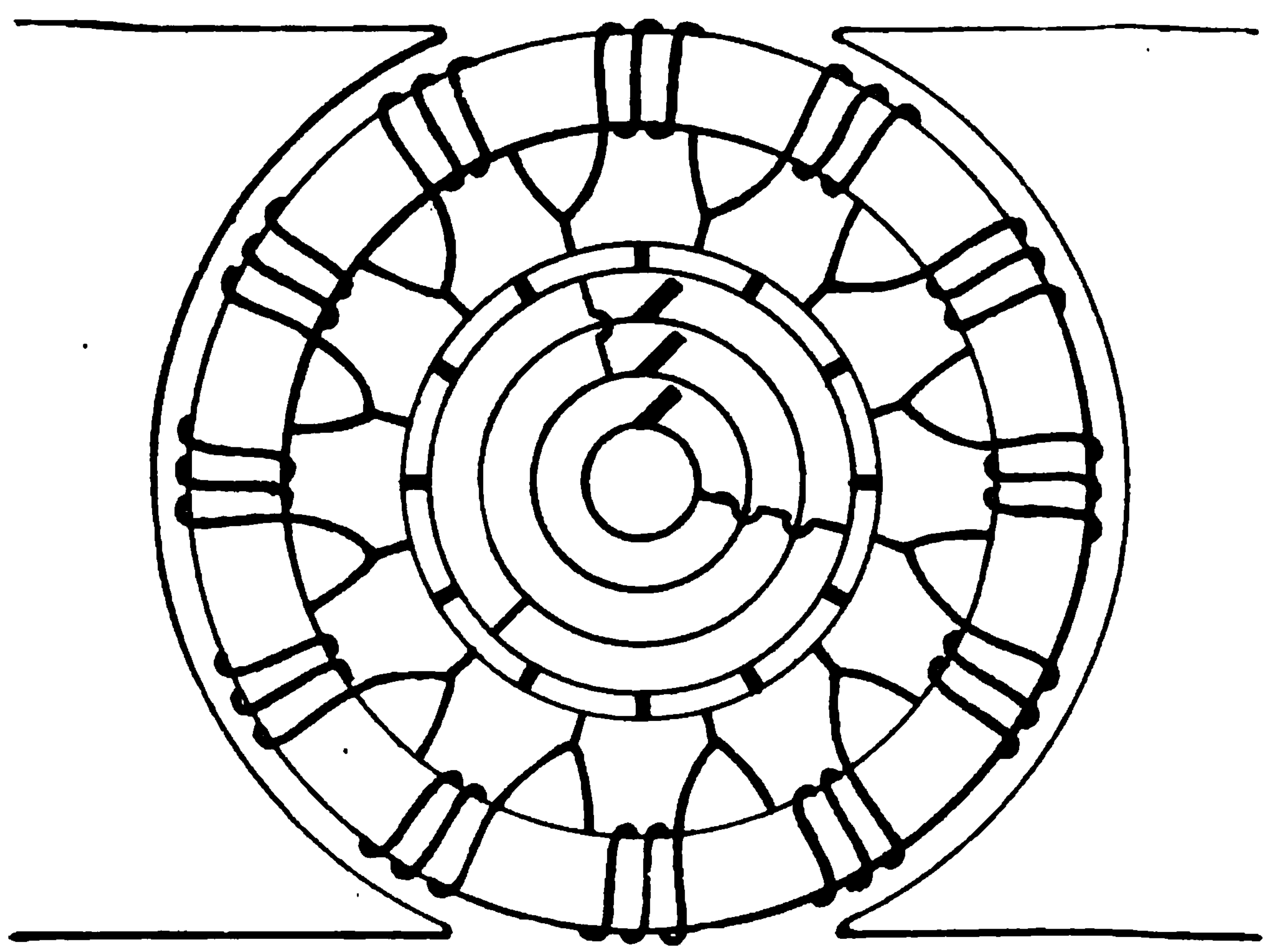


FIG. 149.

can also be driven as an a. c. motor by connecting its collector rings to a proper a. c. circuit and thereby deliver d. c. through the commutator. In such a case it is called an inverted converter. The ratio between the a. c. and d. c. voltage is the same in both cases.

The connection is always delta whether the machine be used as converter, inverted converter or double-current generator. The Y cannot be used as d. c. armatures have closed coil windings. The maximum capacity of a converter is not determined by the heating effect of the current in the armature but by the commutation. Unlike in the double-current generator, the current in the armature of a rotary equals the difference between the

current in the a. c. side and that in the d. c. side. The ratio of transformation is practically independent of the speed or the field strength. Changing the field strength causes only a change of speed. Moreover, change of load does not necessitate a change in field excitation. Regulation is obtained by varying the a. c. voltage, which can be done readily as the current is always taken from a step down transformer.

By varying the field excitation of a converter the power factor of the a. c. system can be varied, over-exciting causing leading currents and under-excitation lagging currents.

Any rotary converter can be started from the d. c. end, but the single-phase rotary will not start itself when supplied from the a. c. end. Polyphase rotaries will start from the a c. end but take an enormous rush of current to do so and for that reason are started as d. c. machines whenever possible.

CHAPTER XXI.

ALTERNATING CURRENT MOTORS.

A. c. motors are divided into two classes, viz.: Synchronous and Induction Motors.

As their name implies, the former must always be in synchronism with the alternator that supplies them with current. That is, their speed multiplied by their number of pairs of poles equals the frequency of the circuit, in cycles, to which they are connected. The speed at which they run can, therefore, only be changed by a variation of the frequency of the driving current, since the number of poles can hardly be altered. Moreover, they must have their fields excited by some d. c. source. They are built to operate on either single-phase or polyphase circuits.

A single-phase synchronous motor, however, will not start up of its own accord when supplied with current, because the alternating current flowing in the armature tends to make the motor run first one way and then the other. If it is brought up to proper speed by some auxiliary means and then connected to an a. c. circuit it will continue to run even after the auxiliary source of power has been removed, being then driven by current from the line. Any alternator will run as a synchronous motor when receiving current from a similar alternator, provided, of course, it is first brought up to synchronism.

A polyphase synchronous motor will start from rest when supplied with current, since the current in one of the windings commences to flow before that in the other windings has ceased. They must be started without load as they take a heavy starting current, in fact will not start under heavy load. Since the speed can not vary as long as the frequency of the circuit to which they

are connected remains constant it might be supposed that their current consumption is always the same. Such is not the case, however. If a synchronous motor running entirely without load had no friction at all its c. e. m. f. would be exactly in opposition to the line e. m. f., hence, no current would flow, that is the motor would not only be in synchronism, but would also be in phase with the alternator. As soon as we load the motor, however, the latter will lag a trifle behind the alternator, that is, be a trifle out of phase with it, hence the c. e. m. f. would no longer be directly opposed to the line e. m. f., and therefore current would flow. The amount of this flow will depend on the amount of the lag of the motor behind the alternator, or upon the phase displacement. Let it be well understood that this is not due to a change of speed but to the fact that the maximum e. m. f. of the motor armature occurs just a trifle later than that of the alternator. The heavier the motor is loaded the farther it will lag behind, and if the load is increased beyond the capacity of the motor, the phase displacement will throw the motor out of step, thus causing it to stop.

Synchronous motors are very useful on transmission systems feeding induction motors and having, therefor, low power factor, since by over-exciting their fields they will produce leading currents, thereby tending to neutralize the lagging currents produced by the induction motors and thus increasing the power factor. Their fields can be adjusted so that their power factor will be one or unity for any load and the power factor will not vary as long as the load is constant. A change in the load will necessitate a readjustment of the field, as a decrease in the load will cause leading currents and an increase of load will cause lagging currents. They ought really only be used where the load is comparatively steady, as heavy load fluctuations cause them to produce inductive disturbances on the line.

When a synchronous motor is started the field current should be opened and the armature connected to the a. c. supply. The field is excited when the motor is near synchronism, which is indicated by some synchronising device as in the case of two alternators being connected together. The field coils are generally connected to a switch which interrupts their series connection for the purpose of limiting the induced e. m. f. to the value of a single coil. Should the field coils remain connected in series the induced e. m. f. therein might, on opening the circuit, rise to such a value as to cause damage to insulation.

A copper shield is usually placed between the pole-pieces and over a portion of the tip, or a copper strap is placed around the pole-pieces and covering part of the pole-tip, for the purpose of preventing "pumping" or "hunting." When two or more motors are connected to the same circuit and the load on one of them varies considerably this trouble will occur if the field is not

adjusted for the change in the load. The above mentioned devices however, make it unnecessary to regulate the field strength to suit a varying load.

The Induction Motor does not run in synchronism with the alternator. They are made to run on either single or polyphase circuits, though most of them are used on the latter. This is probably due to the fact that until comparatively recently no single-phase induction motors were self-starting; that is, they had to be brought up to speed by some auxiliary device. This difficulty almost entirely precluded their use. For several years past, however, self-starting single-phase induction motors have been on the market and are now extensively used in sizes up to 25 and 30 horse power.

The action of the induction motor is based on the principle of the revolving magnetic field. If we place a compass in a magnetic field, say into one of four poles, as shown in Figure 150, and we cause current to flow through the coils of A and C in such a manner that one will have N-polarity and the other S-polarity, the

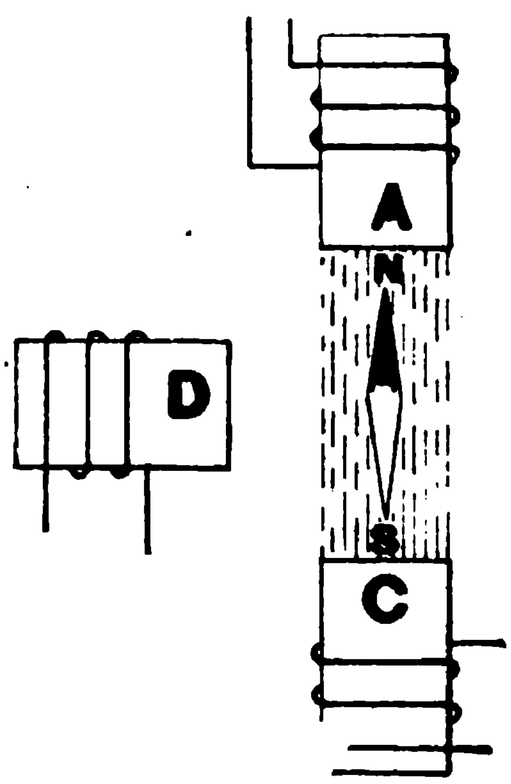


FIG. 150.

compass needle will place itself parallel to the axis of the poles. Now, if we connect the four coils so that poles A and B. will have like polarity and poles C and D have like polarity, but opposed to A and B, the resultant flux-paths will be as shown in Figure 151, and the compass needle will move to the position shown, that is, will be midway between the two flux-paths assuming, of course, both fields to be of equal strength. Let us now cut out coils A and C; the flux will then travel straight across from B to D, as shown in Figure 152, drawing the needle around with it. The needle has now completed one-fourth a revolution, and by continuing these changes of connections we could cause the needle

to rotate continuously if we effect the change fast enough to prevent the needle from returning to its natural N and S position and if we make our changes so that the magnetic polarity will always proceed in the same direction. The same will occur if we substitute an armature for our compass needle.

An induction motor consists principally of a moving element called the rotor and a stationary element called the stator. It makes no difference whether the rotor or stator is used for the armature or the field, though the field is generally the stator. The rotor consists of a laminated iron core, in the face of which are imbedded copper bars or rods, each of these bars being secured at each end to a heavy copper ring, thus forming a sort of squirrel cage. The result is an armature with a very low resistance, the winding being short-circuited. Currents are induced in this short circuited winding which react upon the field thus causing rotation

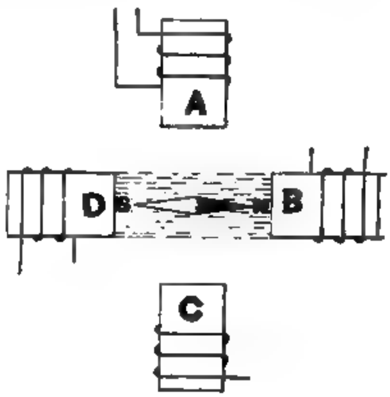


Fig. 151. Fig. 152.

of the rotor. The magnetic polarity of the rotor moves with the rotor, unlike that of a d. c. motor armature, the magnetic polarity of the latter always remaining in practically the same position. The rotor is therefore precisely the same as the rotating compass needle. It is as if the poles on the rotor were trying to catch up with the constantly revolving polarity of the field, and it is this tendency that causes the rotor to revolve. They can never revolve quite as fast as the magnetic field, but their speed, or what is the same thing, the speed of the rotor may be considerably less than that of the rotating field. The difference between the two speeds is called the slip, usually expressed in per cent of the synchronous speed. The slip varies with the load, being very slight at no load and, on an average, about three per cent. on full load. In small motors the slip may be as high as five per cent or more.

The motor can be loaded to such an extent that the slip exceeds this amount, and if the load is increased to such a point that the slip becomes too great the motor will stop.

The speed of the rotor always equals the synchronous speed minus the slip. For instance, if we have a motor having 2 pairs of poles running on a circuit whose frequency is 60 cycles the synchronous speed is

$$\frac{60}{2}=30$$

revolutions per second, or $30\times 60=$ 1800 revolutions per minute. If at full load the slip equals 3 per cent the speed of the rotor would then be 100%—3% of 1800= $1800\times 97\%=1746$ revolutions per minute. A motor having double the number of pairs of poles would have half the speed for any given frequency.

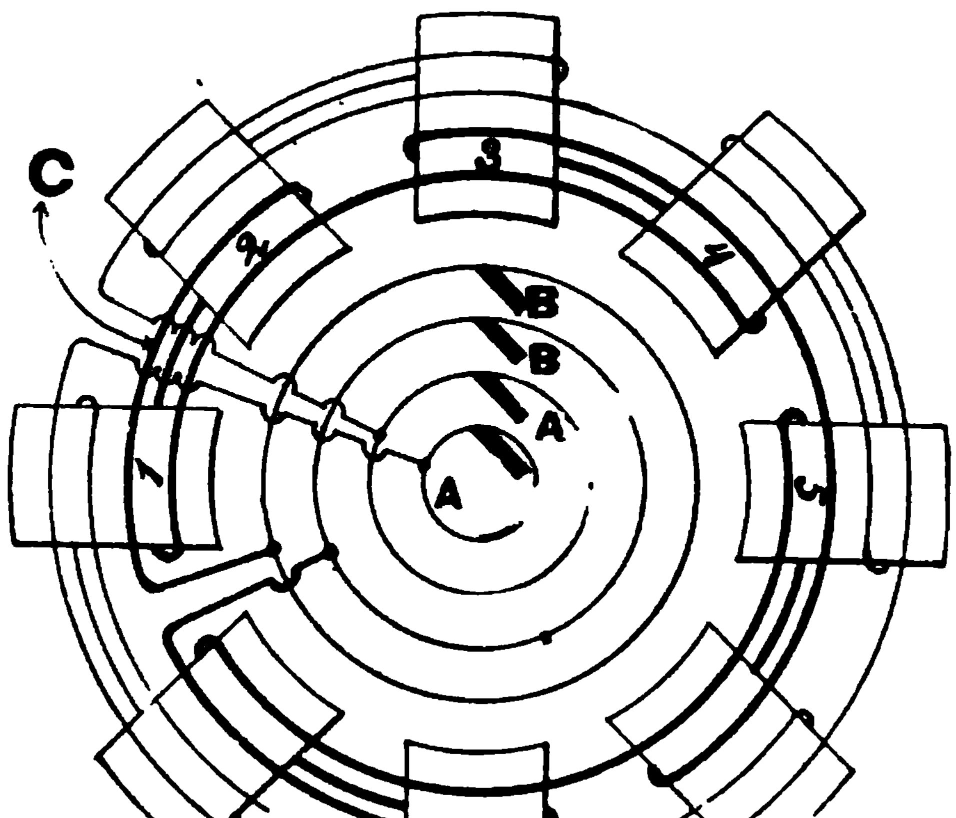


FIG. 153.

These motors generally run better the lower the frequency, some running on circuits having as low a frequency as 25 cycles, although they give excellent results on 60 cycles, which is a standard frequency for lighting purposes. Incandescent lights can not be burned on a frequency lower than 40 cycles without noticeable "winking."

The field structure, usually the stator, is built up of sheet iron punchings and has inwardly projecting teeth. The winding is arranged so that, on a two-phase motor, one coil will be wound around two teeth, being wound so that each coil is opposite to its

neighbors all the way round, all being connected in series; that constitutes the winding of phase A. The winding for phase B is wound precisely the same except that its coils do not embrace the same pairs of teeth that are embraced by the coil of phase A, but instead go around one tooth of one pair and one tooth of the next pair and so on all around. Figure 153 shows the arrangement diagrammatically. In a three-phase motor each coil would embrace three teeth instead of two. Let us see how this method of winding will produce a revolving field. In the figure some of the teeth are marked with numbers and some of the coils with letters. It is not necessary to mark them way around. Say at a given instant the current is maximum, entering brush B, and flowing around teeth 1 and 2 in coil C in such a way as to make their magnetic polarity north; since the neighboring coil is wound in opposite direction evidently teeth 3 and 4 will be of opposite polarity. At that instant no current flows in any of the coils of

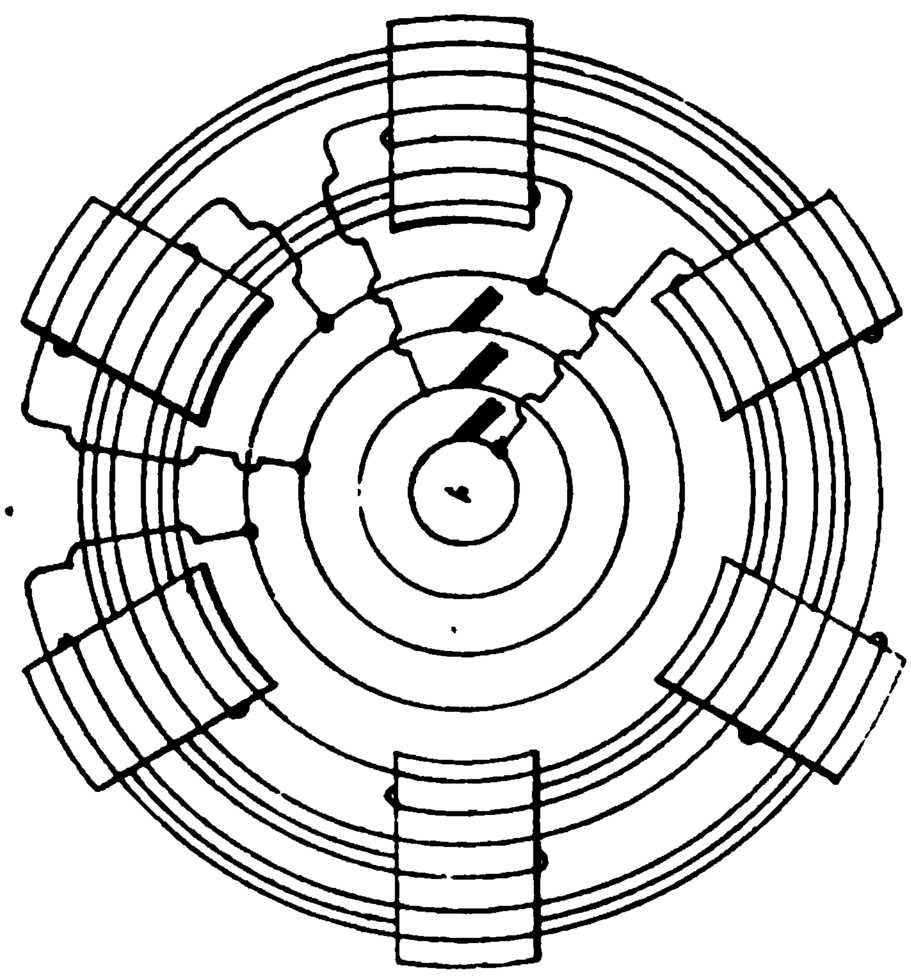


FIG. 154.

the other phase. For greater clearness phase A is shown light and phase B dark. Immediately thereafter, that is when the current in phase B has gone through one-eighth of its cycle, the current in phase A will have risen to a value equal to that of phase B which is now decreasing. Both currents will have the same direction and the result upon the teeth is that the current of phase B still tends to make teeth 1 and 2 have N-polarity and teeth 3 and 4 S-polarity; the current in phase A, however, tends to make teeth 2 and 3 a south pole and 4 and 5 a north pole. The two currents being equal at this instant the result is that teeth

2 and 4 are neutral and tooth 1 remains a north and tooth 3 remains a south pole. So on all around the ring every alternate tooth is neutral and the remaining ones are alternately of S and N polarity. When the current of phase B has gone through 90 degrees or $\frac{1}{4}$ of a cycle it will be zero, but the current in phase A will be maximum and still be flowing in the same direction, hence teeth 2 and 3 are now a south pole and teeth 4 and 5 a north pole. The same relative changes will have taken place entirely around the ring. During the next equal length of time the same changes would take place due to the current in phase A, except that the start would be made from tooth number two, instead of from tooth number one. Thus it will be seen that the poles shift around one tooth or half a coil-width with every quarter cycle, or four teeth (double the width of one coil) during a complete cycle. To reverse the direction of rotation simply reverse one of the phases.

The action of a Three Phase Motor is similar, the only difference being that three currents have to be considered. Figure 154 is a diagram of the field of a three-phase motor, neighboring coils of each phase also being wound opposite, as in a two-phase motor. To reverse the direction of rotation simply reverse any two of the three wires leading to the motor.

Induction motors take a very heavy starting current, even if started without load. The reason is that at starting the rate of cutting of lines of force by the armature is a maximum, hence the current therein and its consequent reaction upon the field is also

FIG. 155.

greatest. This excessive reaction greatly distorts and weakens the field and by so doing reduces the impedance of field coils permitting a heavy flow of current thereby. The torque is also much reduced by this weakening of the field. As soon as the motor starts up of course the rate of cutting of lines of force by the armature conductors diminishes and the reaction upon the field consequently also becomes less. When the motor has attained full speed the velocity of the armature is nearly the same as that of the field, hence there is then little cutting of lines of force. Evidently, the greater the resistance of the armature the less field distortion there will be at starting, hence the greater the starting torque. But if the resistance of the armature is increased beyond a certain point its speed variation with a fluctuating load will be excessive, and for that reason it is made low. To provide for the necessary resistance to keep down the field distortion and consequent loss of torque at starting an auxiliary resistance is provided, it being connected in series with the armature conductors at the start and cut out as the rotor speeds up. This can be done either by hand or automatically by means of a centrifugal arrangement. In the latter case the resistance is placed within the core of the armature, when the latter is the rotating part.

By using this auxiliary resistance great starting torque is obtained without sacrificing the speed regulation, although it complicates the machines somewhat. This disadvantage is more than offset, however, by the advantage derived.

Single-phase motors will run on single-phase circuits, precisely the same as polyphase motors, after having been brought up to speed. Various devices have been brought out to enable the single-phase motor to start itself from rest, such as "phase-splitting" and starting the motor as a d. c. machine by means of a commutator.

The Wagner self-starting single-phase induction motor, see Figure 155, belongs to this class, its armature being practically the same as that of a d. c. motor. The commutator, however, is radial, instead of horizontal, that is, the bars extend out radially from the shaft instead of being parallel to the latter It, therefore has the appearance of a disc, and the brushes do not make contact on the periphery of this disc but on the face of it, as can be seen by Figure 156 which is a cross-sectional view of the motor. A centrifugal arrangement is shown which is so adjusted that when the motor has attained the proper speed the weights will fly out, pushing forward a sleeve upon which is mounted a copper short-circuiting ring, this ring sliding into the circular space within the commutator. The same movement also pushes the brushes away from the commutator. As will be seen

from the figure, the weights act against a spring. When these weights are out the armature winding is disconnected from the supply circuit by reason of the removal of the brushes from the commutator, and also, the winding is short-circuited owing to the copper short-circuiting ring making contact with all the commutator segments. The motor then operates exactly as a polyphase induction motor. The short-circuited armature winding closely resembles the squirrel cage winding, the only difference being that the currents must flow along the individual coils instead of choosing their own paths.

These motors will stand considerable overload and even if overloaded too much they will simply stop. Should the overload be of short duration the motor will resume its normal speed immediately after its removal, because as soon as the speed falls the centrifugal force of the weights is no longer sufficient to hold them out against the tension of the spring, hence they are forced inward, the armature winding is no longer short-circuited and the brushes are again bearing on the commutator, and, as a result, the motor is again in the starting position.

Figure 157 is a diagram of the method of connecting this motor to the supply circuit when only normal torque is required. In the cases where an overload must be brought up to speed the connections are as shown in Figure 158. The motors have three terminals mounted on a terminal board as shown. The middle terminal is called the loop connection and is used for the starting

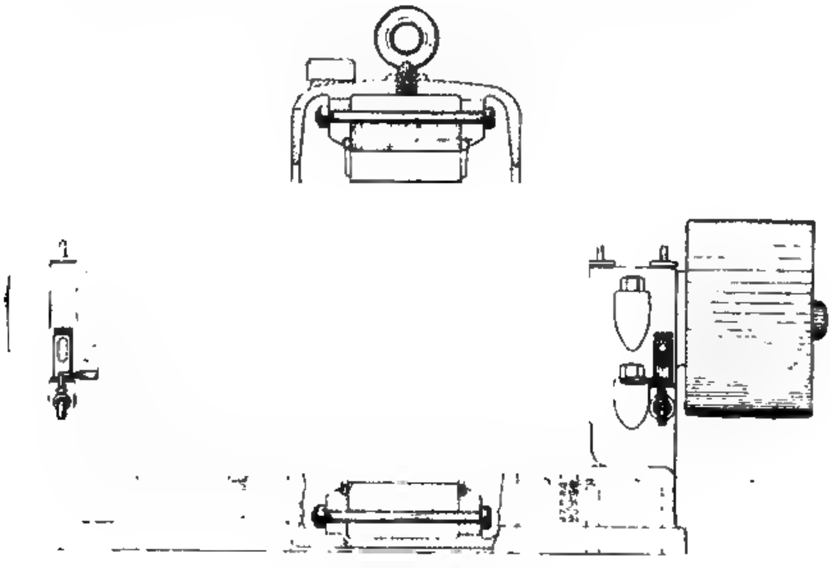


FIG. 156.

position when excessive starting torque is needed. As soon as the motor has attained full speed the double throw switch is thrown into the running position. The loop connection increases the rated capacity of the motor and enables it to readily bring a 50 per cent or even a 75 per cent overload up to speed from rest.

When one of these motors of 10 K. W. capacity or over, is installed on an incandescent lighting circuit, it is desirable that the starting current be limited, in order to avoid too great a drop

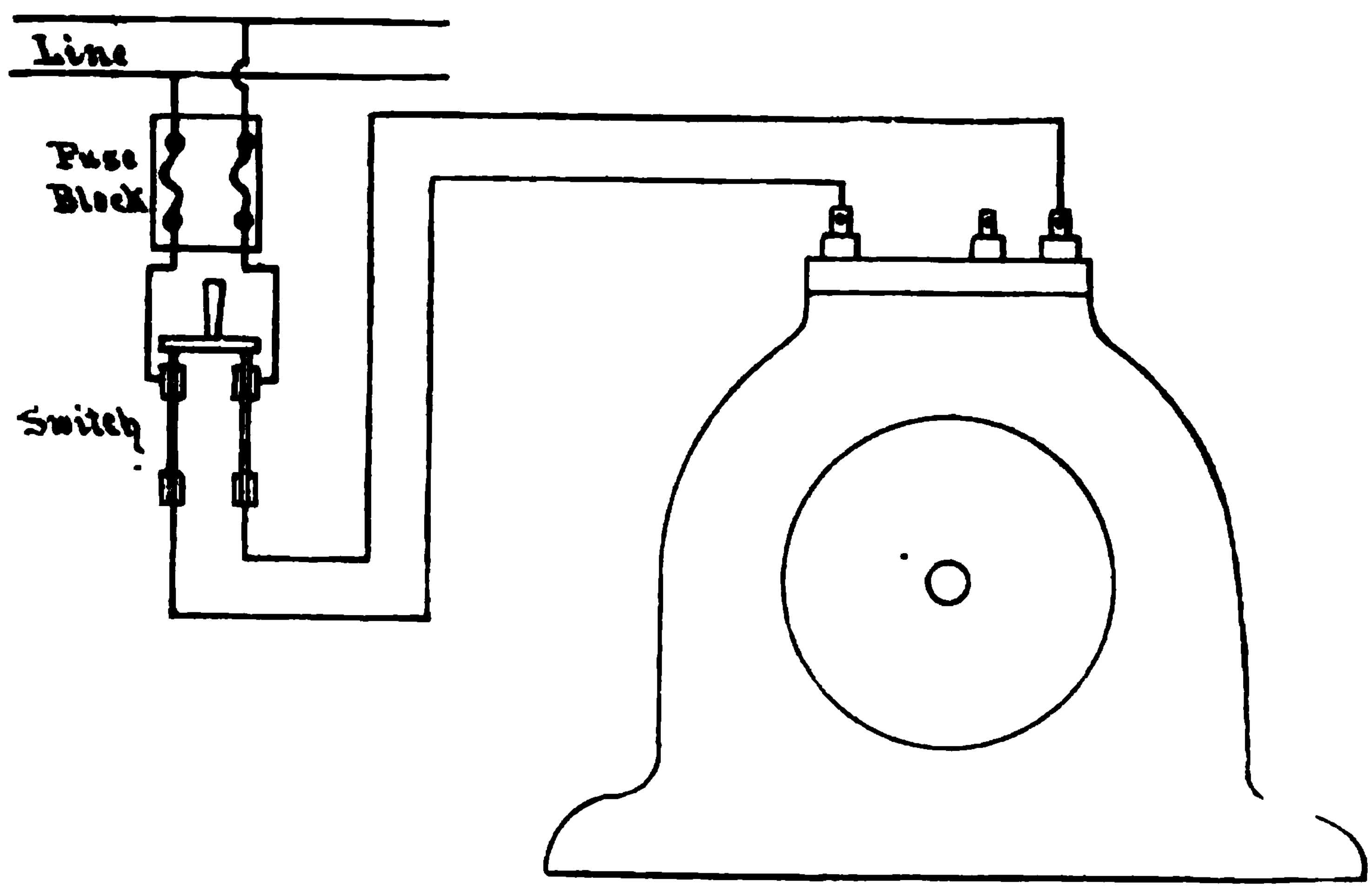


FIG. 157.

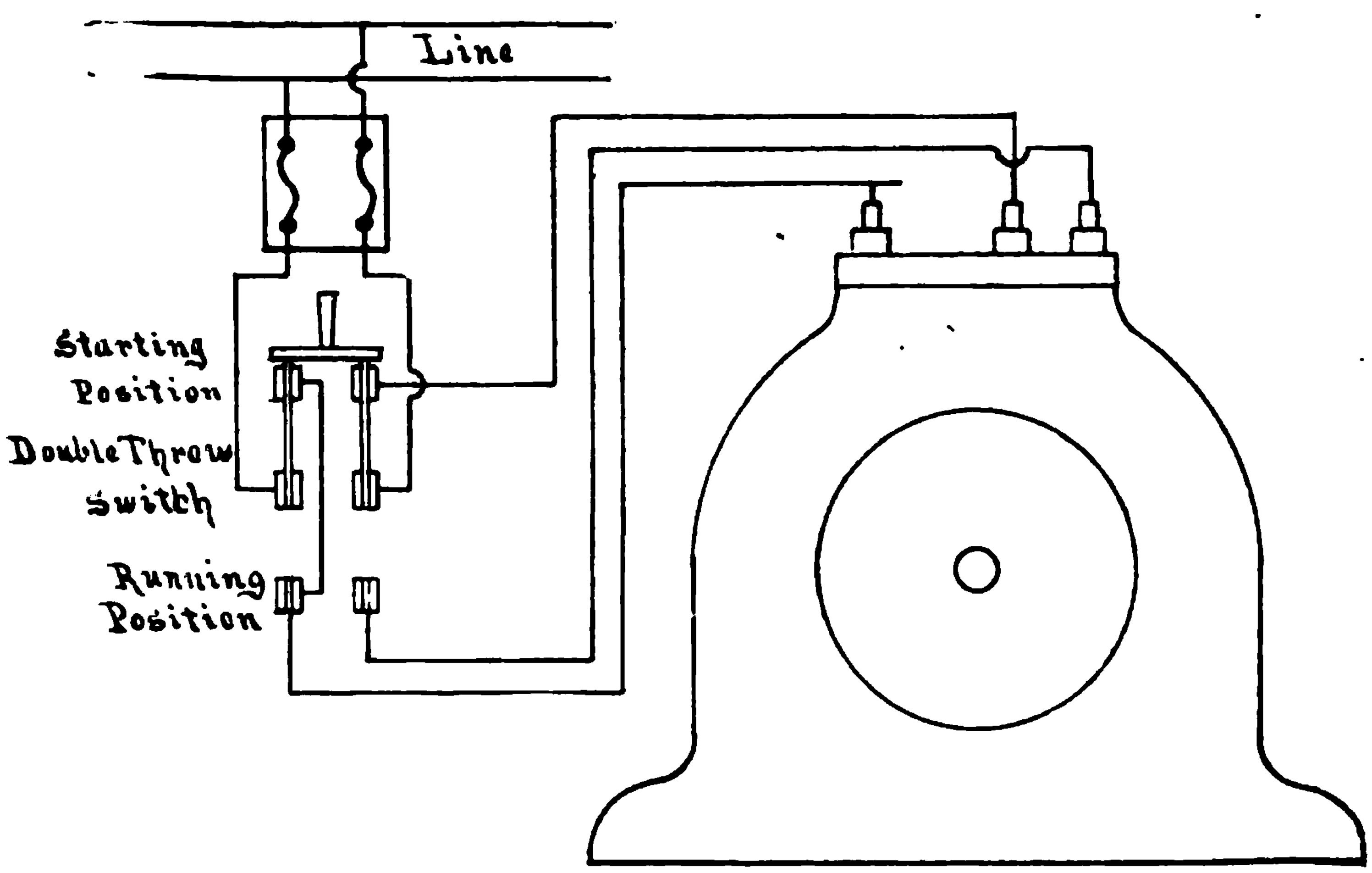


FIG. 158.

in the line voltage, and for this purpose a small auto-transformer is used, a diagram of connections being shown in Figure 159. The motor can be started up in either direction by simply shifting the brushes from one side to the other.

These motors are giving very good satisfaction where starts and stops are infrequent. Numerous starts would of course soon destroy the commutator, it not being built for continuous service. When starting occurs not more than five or six times a day, the life of the commutator is fully as long as that of a d. c. commutator, if not longer.

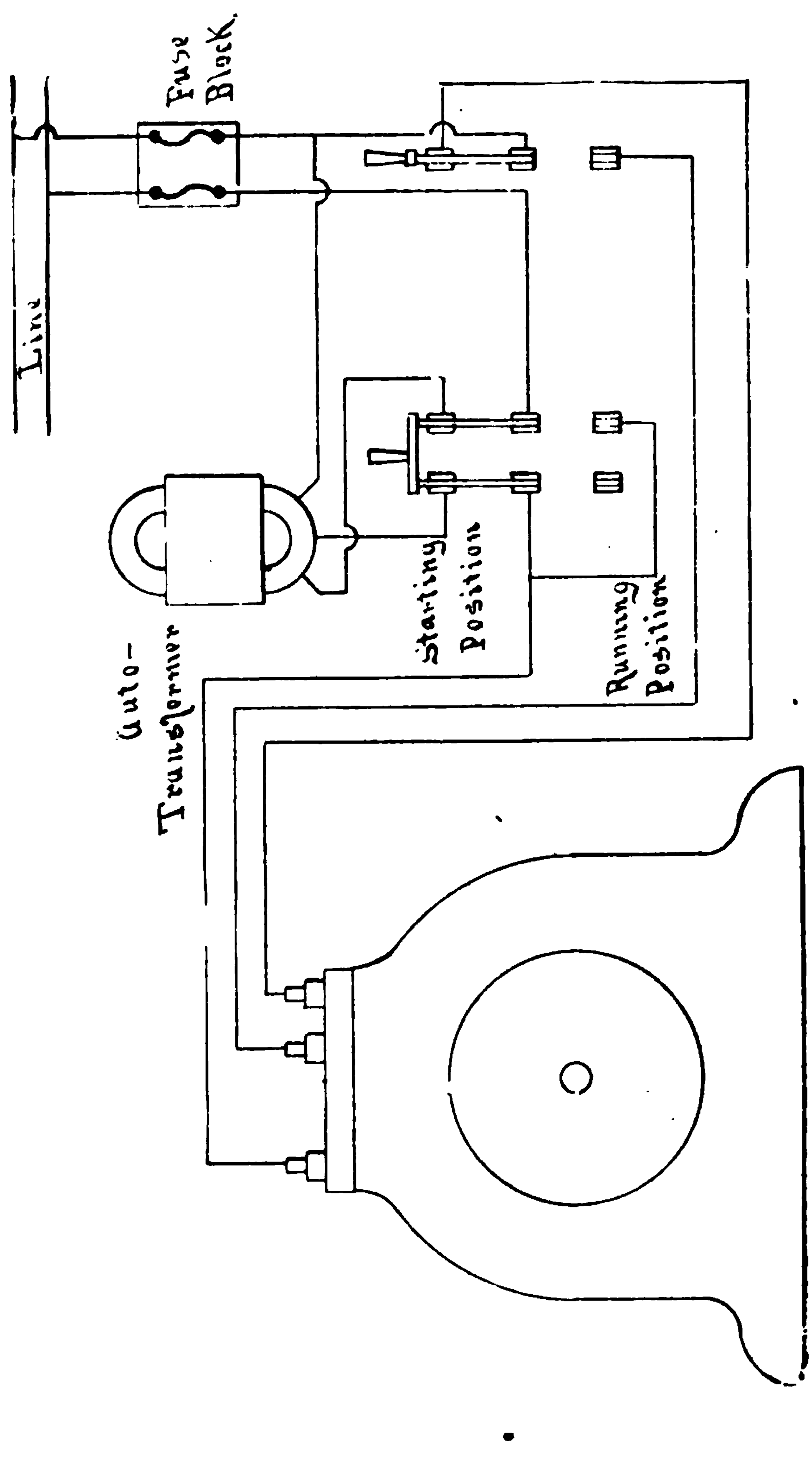


FIG. 159.

CHAPTER XXII.

DISTRIBUTING AND TRANSMISSION SYSTEMS.

Of these there are several, each having its own particular advantage. Where the distance from generator to the farthest lamp is comparatively short, as for instance, in stores, factories, etc., the two-wire system is generally installed, using one or more 110-125 volt d. c. generators, usually compound-wound, and connected together in parallel in case more than one is used. This is the simplest type of installation and requires little attention and no great electrical knowledge on the part of the man in charge. The voltage is entirely within safe limits, and both arc and incandescent lamps can be economically operated from the same machine, as can also motors if they be not too large, and not too far removed from the generator. Such an installation is shown diagrammatically in Figure 160.

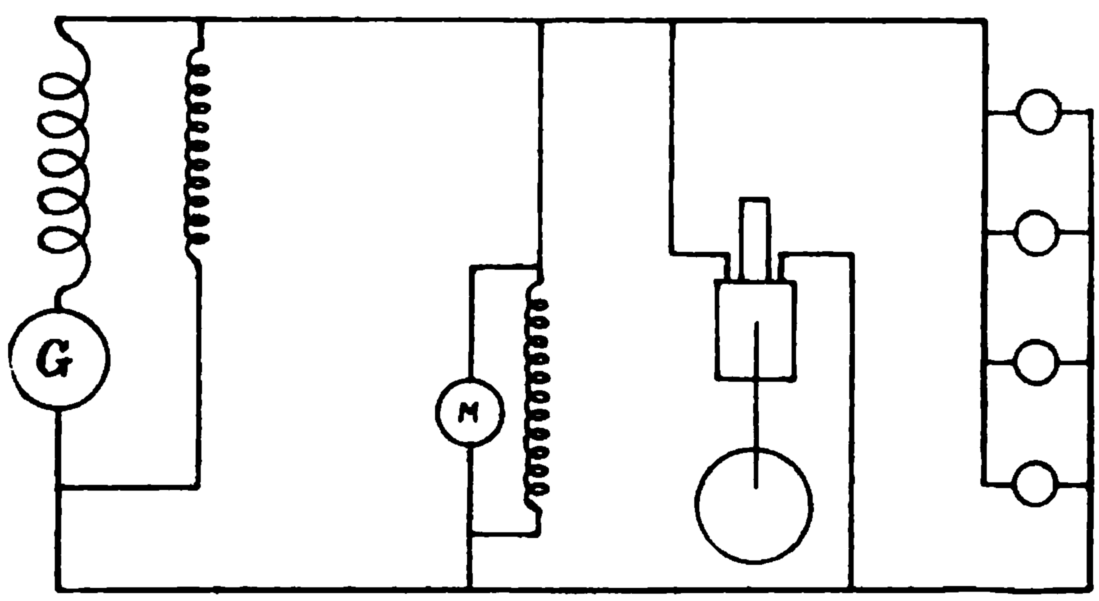


FIG. 160.

Where the distance becomes greater, especially if the load is also greater, as for instance by a number of motors of considerable capacity, the simple arrangement shown above would not be economical, or if the wiring were made large enough to keep the loss within reasonable limits, the expense of the copper would be prohibitive. As the line-loss increases as the square of the current and decreases as the square of the voltage employed, it is clear that with any given size of wire, if the voltage is 220, a given amount of energy can be transmitted at one-fourth the loss of a 110 volt system. Incandescent lamps can be had to burn on this voltage, though they are not so efficient as 110 volt lamps, nor have they as long a life. Arc lamps are usually connected two in series, on 220 volt circuit; where two are in series and one is not to go out when other does, they must each be equipped with a cut-out, which, when the circuit of one lamp opens, will permit the passage of current. It must cut in a resistance, however, equal to that of one lamp,

so that the other lamp does not get too much current. This is wasteful, where only one lamp is burning or where only one is needed; one or more generators can be used, being connected in parallel. This system, although having a larger scope for given loss and given first cost than the first, has also a narrow limitation as to the distance at which it can economically transmit energy. Moreover, there is an objection to bringing the comparatively high voltage within reach of everybody that may handle an incandescent lamp; half a mile is the limit to which energy can be economically transmitted at a reasonable outlay for wiring.

The 110-220 volt 3-wire system overcomes the objection against the preceding system as to inefficiency of lamps and high voltage. Its range is practically the same as the 220 volt 2-wire system.

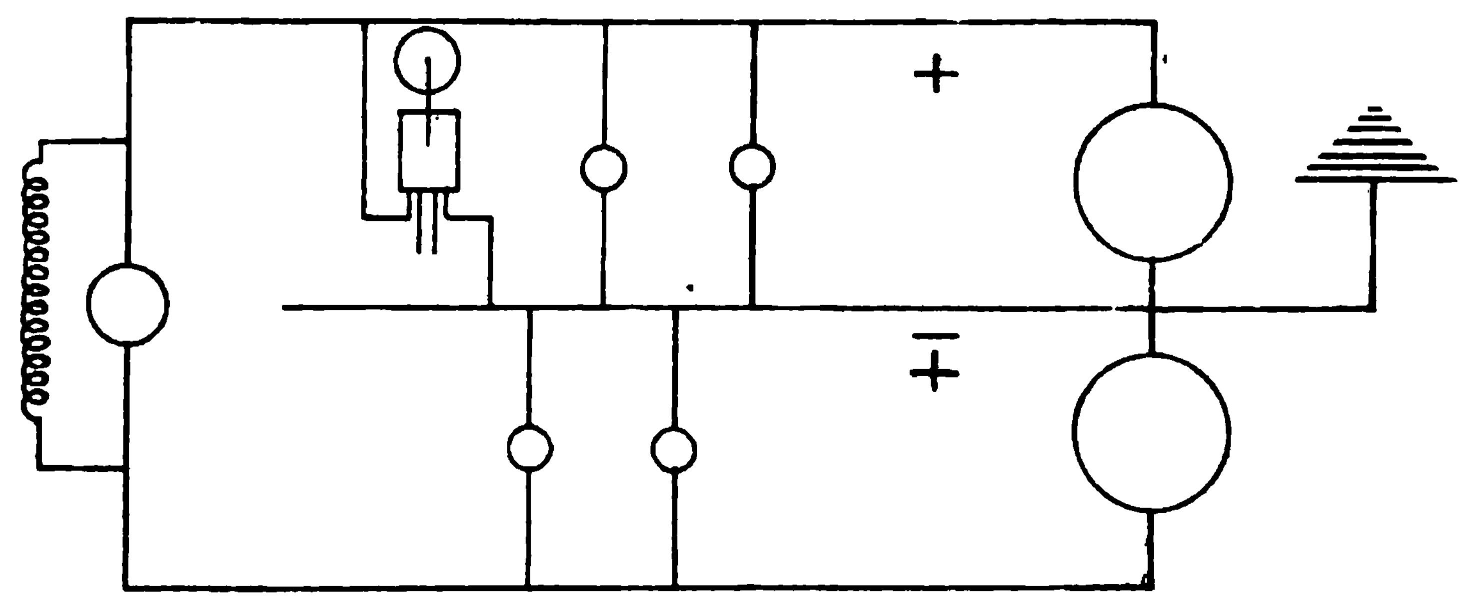


FIG. 161.

Two 110-volt machines are connected in series, as shown in Figure 161, and three line wires brought out. The incandescent and arc lamps are connected to the middle and either one of the outside wires. If it is desired to run motors also, they are usually connected to the two outer wires, though they could be connected the same as the lamps, if desired, but would in that case take double the current for any given output. Fan motors are connected same as lamps, since they take about the same amount of current as a 16 c. p. lamp.

If the two sides of a 3-wire system be perfectly balanced, that is have the load between the middle and one outer wire equal to the load between the middle and the other outer wire, no current will flow through the middle, or as it is called, the neutral wire. Therefore, if the balance could be maintained constantly, the neutral wire could be taken out entirely; but as the balance is never perfect the neutral wire always carries a little current, the exact amount being the difference between the current in one side and that in the other side. If the neutral wire should become disconnected from the dynamos when the loads were unbalanced the

lamps on the lighter side would burn at a higher, and those on the heavier side would burn at a lower c. p. than the normal. The magnitude of this effect would depend on the amount of the difference between the two sides of the system; the unbalancing could be carried to such a point that the lamps on the lighter side would be burned out.

The neutral wire is generally grounded at the station; that prevents the possibility of getting a shock of the combined voltage of the two machines through the ground. If the neutral were not grounded, and a ground would occur on say wire A, at G, Figure 162, a person in connection with the ground would get

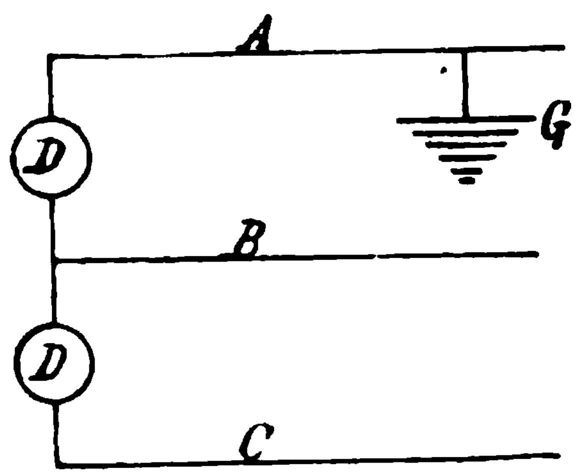


FIG. 162.

220 volts by contact with wire C. By grounding the neutral, B, only 110 volts can be obtained from either wire to ground. To be sure, if one of the outer wires were to become grounded it would cause a short-circuit on that side of the system and blow the fuse between the point where the ground occurs and the source. Say the ground or short-circuit were only of sufficient duration to blow the neutral fuse; it is possible that this would not be noticed at once by the man in charge. Now if the load is unbalanced, the lights on one side will burn bright and those on the other side will burn dim, although the voltage at the station will be normal; replacing the fuse will remedy the trouble; if the fuse in the outer wire had blown, of course all the lamps beyond the fuse would be out.

It is necessary that both machines have the same current capacity and the same per cent of compounding if compound machines are used. The advantage of the system lies in its economy of first cost, low line loss, absence of high voltage at the lamps and the ability to burn at least half the lamps should one machine fail. The disadvantages are the necessity for two machines regardless of the percentage of load, running two small machines instead of one large one (the efficiency of the smaller machines being less) and double wear and tear.

Some 3-wire systems employ two 220-volt generators, giving 220 volts between either wire and neutral, and 440 volts

between outer wires. The voltage being double that of the 110-220-volt system, the distance to which a given amount of power can be transmitted with given loss and given size wire is quadrupled, as the line loss decreases as the square of the voltage employed.

Sometimes, instead of having two machines, each of half the capacity of the load to feed a 3-wire system, one machine is installed, capable of carrying the entire load. The voltage of this machine equals the voltage between the outer two wires of this system. The two outer wires connect direct to the terminals of this machine, and a motor-balancer or equalizer set is connected across these two wires. The two equalizer armatures being in series, each has half the voltage of the generator; from between the two armatures, which are on the same shaft, the neutral wire is fed. The arrangement is shown in the

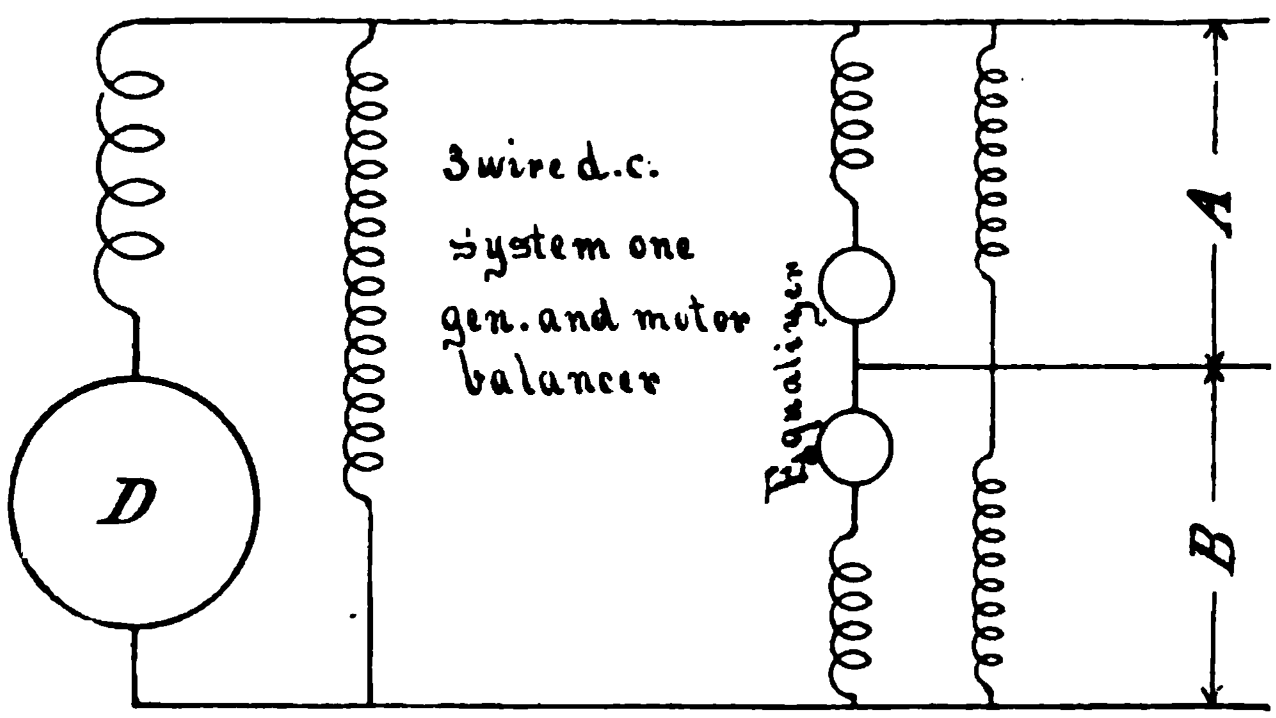


FIG. 163.

diagram, Figure 163. The equalizer set need only be of sufficient size to carry the inequality of load between the two sides; when the two sides are balanced, the balancer runs as a motor without load, and consumes very little power. As soon as side B becomes heavier loaded than side A, a portion of the current will flow along the neutral wire and through A to the negative side of the circuit; in case side A becomes heavier loaded, current will flow from the juncture of A and B along the neutral wire and supply side A with the excess current; this arrangement is also used where it is desired to run 500-volt motors and 110-volt lamps from the same generator. In such a case the two equalizer armatures must have voltages of 110 and 390 respectively; the motors are connected to the generator wires and the lamps between the neutral and that main wire to which the low voltage armatures are connected, and, of course, either arc

or incandescent lamps can be used. The equalizer set need not run when no lights are wanted.

However economical the three-wire system, there is nevertheless, a limit to its economical radius, even with 250-500 volts. The latter will transmit power at a reasonable loss and amount of copper up to about two miles, provided long runs do not have to be made to reach a small number of lamps.

For street and outdoor lighting, series arcs are the most economical as regards both first cost and operation. The high voltage and comparatively small current employed keep the line loss quite low, even on long lines. Series arc circuits are frequently six, eight, and even ten miles in length.

On account of the high voltage employed, this system is not adapted for general interior use; moreover, incandescent lamps can not be operated successfully thereon. That necessitates two different types of machines in a station supplying both kinds of lamps, if d. c. arcs are used. In the early days of electric lighting only d. c. arc lamps were made, a. c. arc lamps then not being much of a success. Fortunately, things have changed since those days, and a. c. lamps of to-day are just as satisfactory as d. c. lamps, in some respects more so.

For both arc and incandescent lighting and power service over large areas and widely scattered loads, the alternating current furnishes the most satisfactory and economical means. The ease and facility with which voltages of any desired value can be obtained thereby, and its adaptability to running motors, arc and incandescent lamps from one generator render it peculiarly fitted for commercial purposes. Only one type of generator is required, no matter how varied the individual requirements of the consumers may be, which greatly simplifies the plant.

A. c. generators or alternators usually supply either 1000 or 2000 volts, which is fed directly to the distributing circuits. Where it is desired to use current a transformer of suitable capacity is put up and its primaries are connected to the line, as shown in Figure 164, where A is the alternator, T the transformer. The low voltage secondaries are then brought into

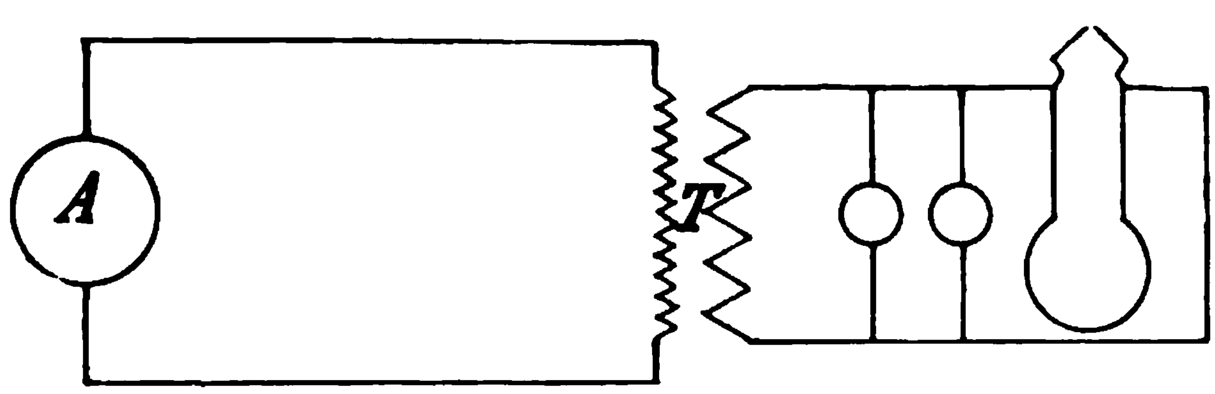
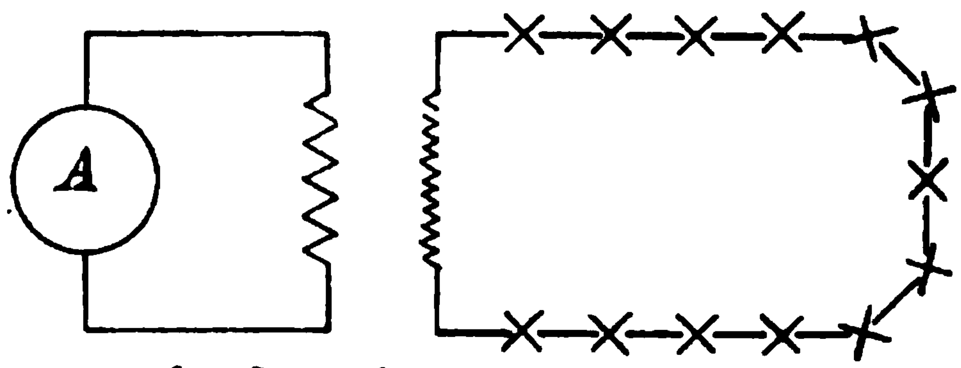


FIG. 164.

the store, residence or other place where the current is wanted and the lamps, motors, etc., are connected in parallel to these secondary wires. As there is no electrical connection between the primary and secondary winding of a transformer, the secondaries are safe to handle, no matter how high the primary voltage. Some alternators give a higher voltage than 2000; however, should it be desired to get more than 2000 volts on a circuit without having a generator of higher voltage, it can easily be obtained by means of a step-up transformer, as a transformer can be used to raise as well as lower the voltage. By this means any desired line pressure can be obtained without an excessive voltage at the generator.

A. c. series arc circuits are usually fed from a constant current transformer, that is, one that will keep the flow of current constant, by varying the secondary voltage. The lamps are connected in series with one another and with the secondary of the transformer; the primary of the latter is connected to the generator, as shown in the diagram, Figure 165.



A. C. series arcs on constant current transformer

FIG. 165.

Another method is to connect a series of lamps direct to the primaries and use a reactance regulator, which automatically maintains the current constant by varying the reactance of the circuit as the load varies. One advantage of this arrangement is that the wire from the last lamp need not be brought back to the station, but can be connected to the nearest point of the primary circuit. Figure 166 is a diagram of the arrangement; in one form of regulator a hollow coil is mounted on one end of a movable arm weighted at its other end in such a manner that it can slide down over one of the legs of the U-shaped magnet core. The coil is connected in series with the lamp circuit; when the circuit is normal the coil is at the top, and as its magnetic circuit is air, the impedance is minimum. As soon as a lamp is cut out the current strength rises; that increases the magnetic pull of the coil on the core, so that the former can overcome the pull of the counter weight, and embrace

part of the iron core, thus increasing the number of lines of force in the magnetic circuit of the coil. This causes an increase in the impedance of the coil so that the current strength is reduced to the normal value. The pull of the coil will, of course, increase, the more of the core it embraces, so that a heavier counter weight is needed in such positions. This is obtained by the movement of the arm, as, when the coil is at the top, the distance between weight and fulcrum is minimum. As the coil goes down and the weight goes up, the distance between the weight and fulcrum is increased, and therefore its force upon the other end of the arm is increased proportionally, owing to the increased leverage; by this means the varying pull of the coil is balanced at every point of the coil's travel. These regulators are not made to take care of a current varia-

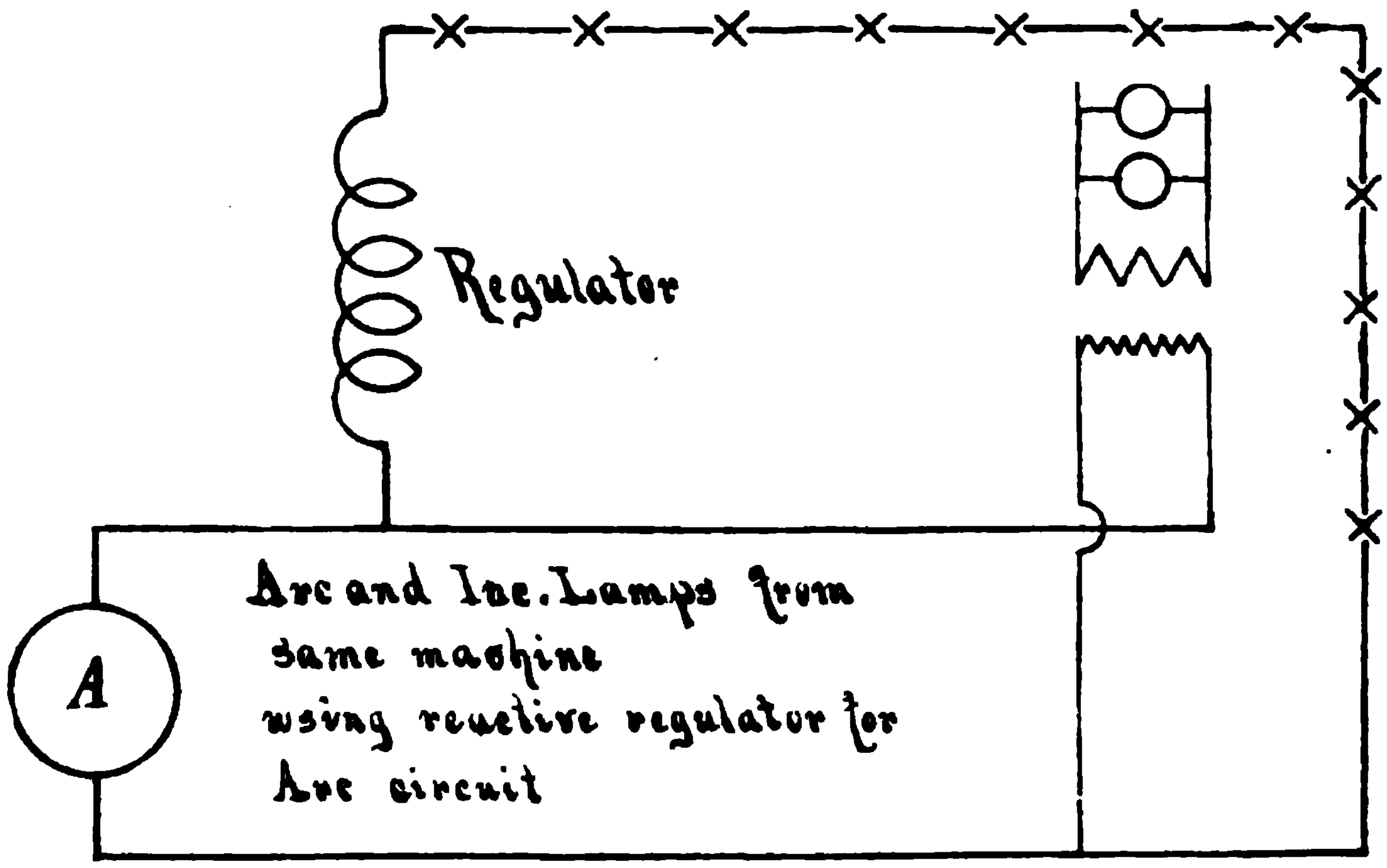


FIG. 166.

tion due to all of the lamps being cut out, because in practice it is seldom that more than two or three are out at once on circuits on which there are only a moderate number of lamps at full load; they can be built to do so, but will be quite bulky. They are built in various sizes to take care of various percentages of load variation, 10%, 20%, 30%, 50%, etc.; thus a 20% regulator on a circuit of twenty-five lamps would regulate the current as long as not more than five lamps were out at one time. A 50% regulator would take care of the change in current resulting from half the lamps being turned off.

Another method of a. c. series arc lighting for both street and indoor illumination is to use transformers of a low ratio of transformation, say three to one, or even one to one, de-

pending on the number of lamps each is to supply; the primaries are all connected in series with the machine and one another, as shown in the diagram, Figure 167. Some lamps are shown connected in the primary circuit; that is permissible for the street lamps. By using the transformer for indoor lamps, only the low tension secondaries need be brought into a building, and all danger is avoided. As the current increases, the armature, owing to the design of the machine, weakens the field sufficiently to reduce the e. m. f. to such a point as to cut down the current to the normal value, giving automatic regulation.

The General Electric Company's system employs a special constant-current transformer, with a movable secondary coil; the primary is stationary. The secondary can move up and down on the core, so as to increase or decrease the distance between the two, thus varying the number of magnetic lines

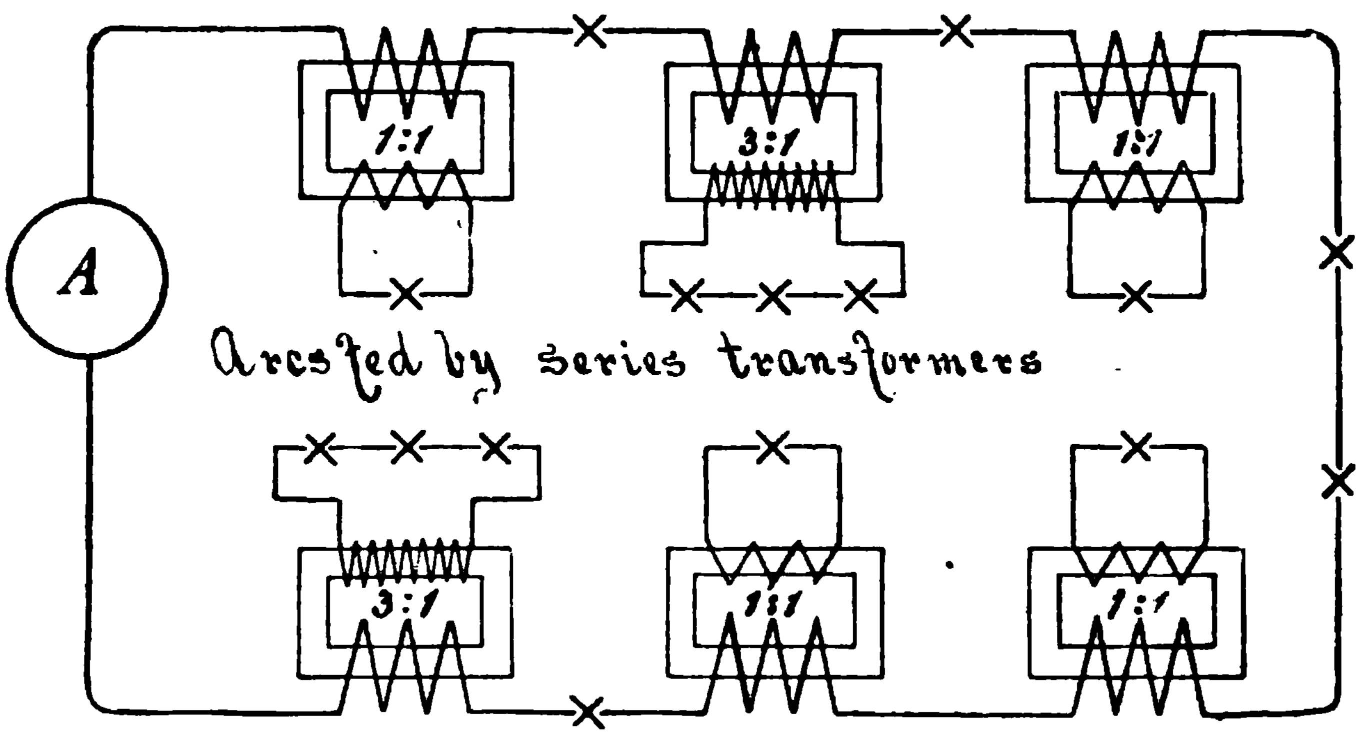


FIG. 167.

through it. When fully loaded it is right up against the primary, and the magnetic flux through it is maximum, and therefore, also, the voltage. The weight of the coil is counter-balanced by a weight passing over an arm to the outside of the transformer. The regulation is based on the fact that when two coils are carrying current whose relative direction is such as to produce opposing magnetic fluxes they will repel one another, the repulsion being proportional to the strength of the current in the coils. As the secondary of a transformer produces a flux that is opposed to that of the primary, evidently the more current that flows in the windings the stronger will be the repellant effect between the two coils. As long as the current is normal the repulsion is not strong enough to move the secondary, even though it is counterbalanced. As soon, however, as the current rises above the normal, the secondary

will be forced away from the primary, and as that reduces the flux or lines of force through it, its e. m. f. is thereby reduced, and the current decreases also. It is placed in an iron case which is filled with oil; besides insulating the windings and carrying the heat from them to the iron case, it also acts as a damper, to check a too rapid movement of the secondary coil. The primaries are connected to the generator, and the lamps are in series with the secondaries; a circuit once started needs no further attention.

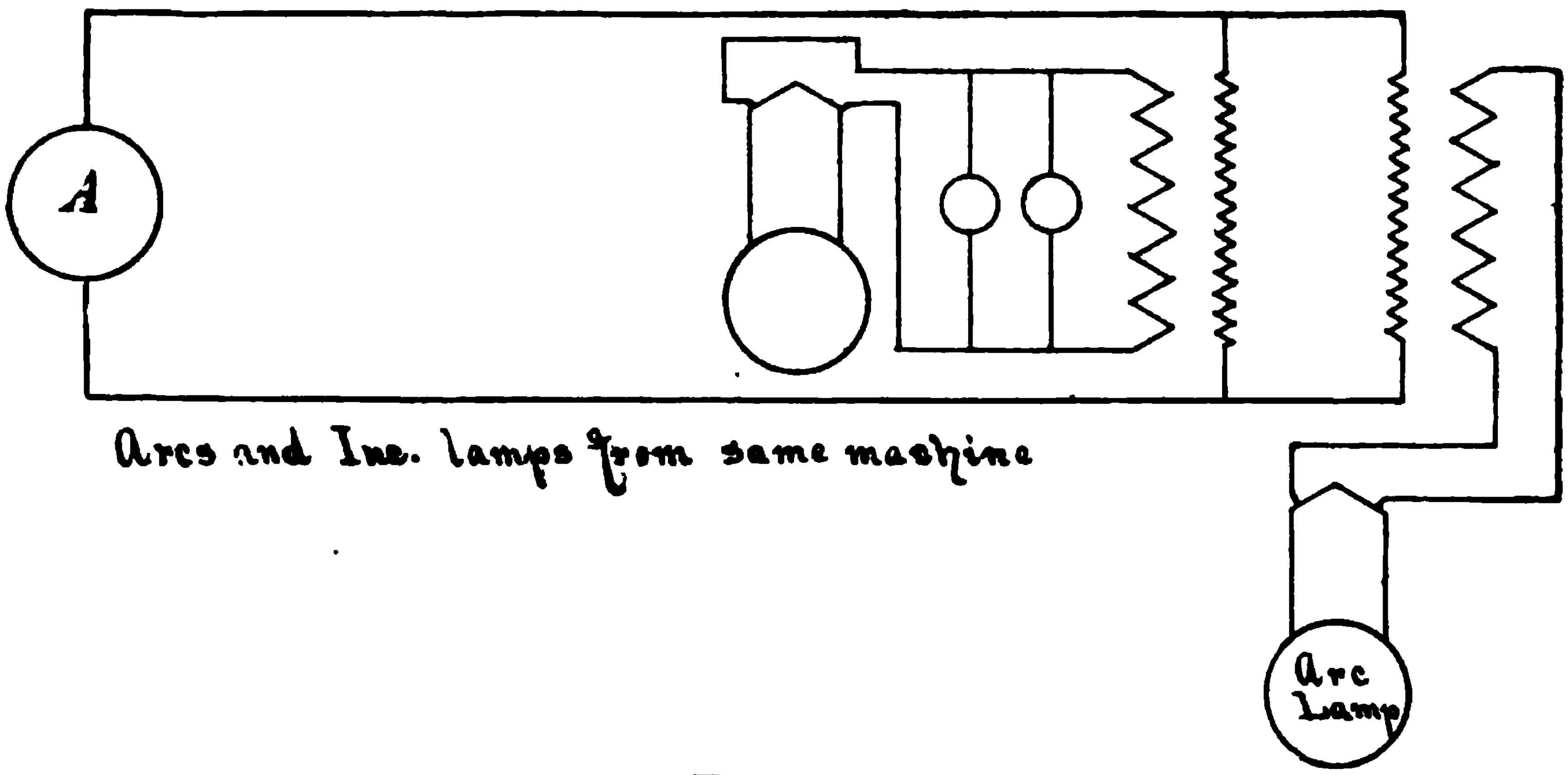


FIG. 168.

Figure 168 shows an arrangement by which both incandescent and arc lamps, outdoor or indoor, can be burned from one alternator, or one pair of primaries, without any regulating devices. The incandescent lamps are fed from the secondaries of transformers as shown, and each arc lamp is fed from an individual lamp transformer, which however, have their primaries connected to the line in multiple, instead of in series, as in some of the preceding cases. Single-phase motors and arc lamps can also be run from the secondaries of the larger transformers. In fact, where arc lamps are installed within reach of a pair of secondary wires no individual lamp transformer need be installed; it is only necessary where arc lamps are placed in locations where there is no incandescent load, as, for instance, outlying streets where there are no private consumers. This is by far the best system where the number of arc lamps is too small to install an a. c. constant current transformer, as it does away with all regulating devices with their attendant complications, although it is less efficient.

Secondary distributing systems should be so laid out as to avoid the use of a great number of small transformers. Every effort should be made to group the different consumers so that a few large transformers can carry the greater portion of the load, as the larger the capacity of a transformer, of a given make, the higher its efficiency. It is also of advantage to have each one working as near as possible on full load, as any transformer is more efficient on full load than at lower loads. Of course the use of small transformers cannot be avoided entirely, as some consumers may be quite a ways removed from others. But there is no reason why the business portion of a small town could not be carried by a couple of large transformers, so placed that about one-half the load is between them, and about half the balance beyond each of them. Transformers with 3-wire secondaries are preferable, as thereby 3-wire secondary distribution can be obtained with a considerable saving of copper and line loss. The arrangement is shown diagram-

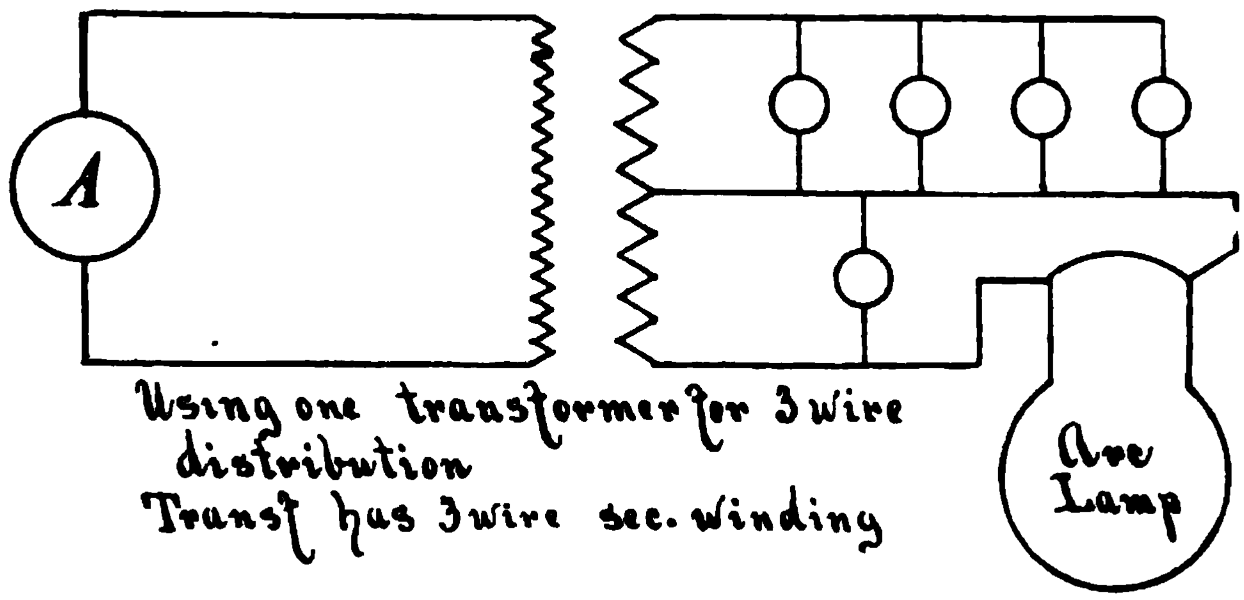


FIG. 169.

matically in Figure 169. Transformers with 2-wire secondaries can be used for 3-wire distribution by connecting the secondaries in series and bringing out the neutral wire from between the point of juncture, as shown in Figure 170, but those with the regular 3-wire secondaries work better; two-wire service can be taken into the consumers premises, if desired. Where there is a large consumer it is better to give him 3-wire service, as it facilitates balancing the load.

All distributing systems, d. c., or a. c., primary or secondary, should be arranged so that they are fed at the center of the load, if possible, so that the drop in the different portions of the system shall be equal. The center of the load is not always the center of the system as measured in feet, but is the distance in feet multiplied by the amperes or watts. Thus, say we are distributing 50 K. W. over 1200 feet, and the various consumers are so located that one-half the load comes within one-

third the distance from one end of the circuit. In such a case the circuit should not be fed in the middle, but should be fed at such a point near the heavier loaded end that the shorter distance multiplied by the amperes or watts it carries shall equal the longer end multiplied by the amperes or watts in the latter. Such an arrangement is not always practical, of course, owing to local conditions.

It should be remembered that unequal distribution is not as great a disadvantage on high tension as it is on low tension systems, as in the former a difference of a few, or even 15-20 volts, is only a small per cent. of the total voltage, and will make no appreciable difference in the burning of the lamps, whereas a difference of 3 or 4 volts, on a low voltage system will materially affect their c. p., if the same voltage lamps are used throughout.

Another method consists in dividing the area to be fed into sections, and feeding each section by means of sub-feeders tapped into the feeders; all consumers are to be fed from distributing mains tapped onto these sub-feeders. Figure 171 shows the

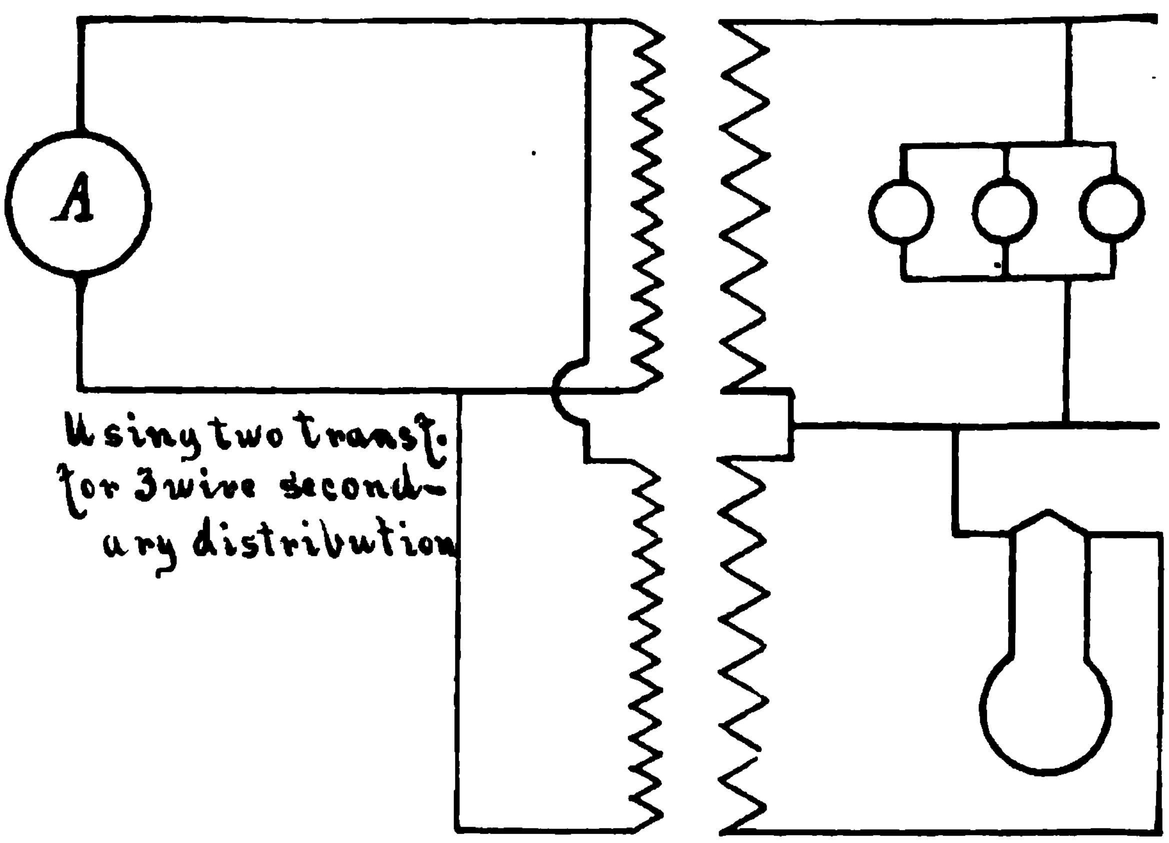


FIG. 170.

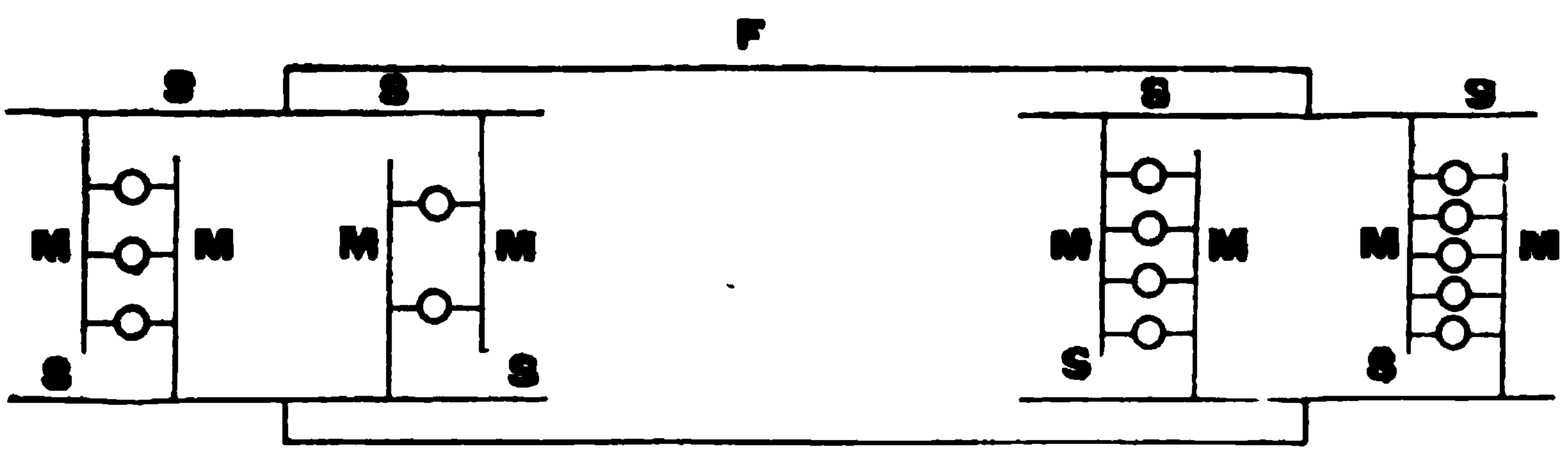
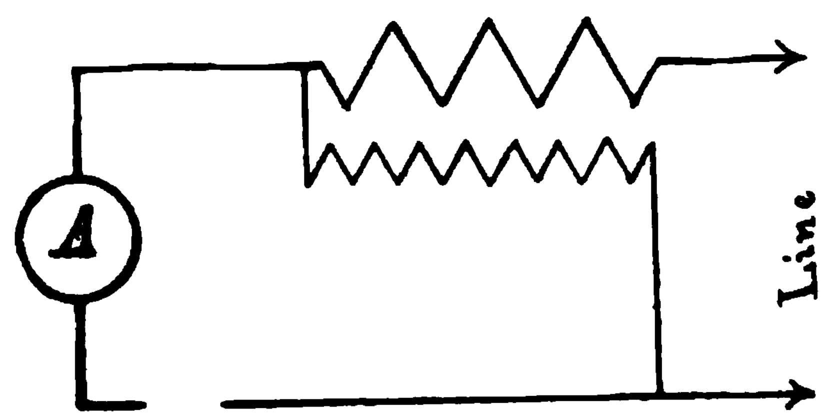


FIG. 171.

arrangement; F F are the feeders, S S, etc., are the sub-feeders, M M, etc., are the distributing mains. By properly proportioning the area of the various sub-feeders a practically equal voltage can be obtained at all points, with good economy in copper; no current to be taken from sub-feeders between the feeders and the distributing mains.

"Tapering," that is, using lamps of lower voltage on circuits farther removed from the center of distribution than on those nearer thereto, should be avoided, as it is never satisfactory. If the distributing and feeder system is properly laid out, tapering will not be necessary, and if faultily laid out it should be changed. Sometimes it occurs that a bunch of consumers require an exceptionally long circuit to reach them, and therefore the drop in such long feeders would be great enough to cause their lamps to burn dim. In such a case, if the system is an a. c. one, take an ordinary transformer and connect its secondary in series with one leg of the circuit whose voltage is to be raised; connect its primaries directly across the two sides of the same circuit.



Transformer connected to boost line Voltage

FIG. 172.

See Figure 172. The secondary voltage will now either lower the e. m. f. of the line or act as a "booster," according to the way it is connected. If it lowers the voltage of the circuit the connections of one of its windings should be reversed. It will boost the voltage of the circuit by an amount equal to its secondary voltage, thus compensating for the drop in the long line. If the boost is too high, connect an inductive resistance into the primary circuit of the transformer, and by varying same the boosting effect can also be varied. Care should be taken that the secondary coils of the transformers are of sufficient capacity to carry the primary current.

With a d. c. system such an arrangement is, of course, out of the question. Large d. c. systems, as, for instance, street railways, use a "booster-set" to compensate for the increased drop in long feeders, either with or without storage batteries.

Figure 173 is a diagram of a booster-set used in some of the low tension d. c. lighting plants. A motor and a series generator have their armatures connected rigidly together and are mounted on the same bed-plate; the motor is usually shunt-wound. The generator is connected in series with one leg of the circuit whose voltage is to be raised. If the amount of iron in its magnetic circuit be large enough it will strengthen the field in direct proportion to the current in the line, hence its e. m. f. will vary likewise, the armature being driven at constant speed by the motor. The e. m. f. of the booster armature will, of course, either assist or oppose the line voltage, depending on how it is connected; thus the line voltage can be either raised or lowered as current increases. Precautions should be taken against the possibility of the generator end being reversed in

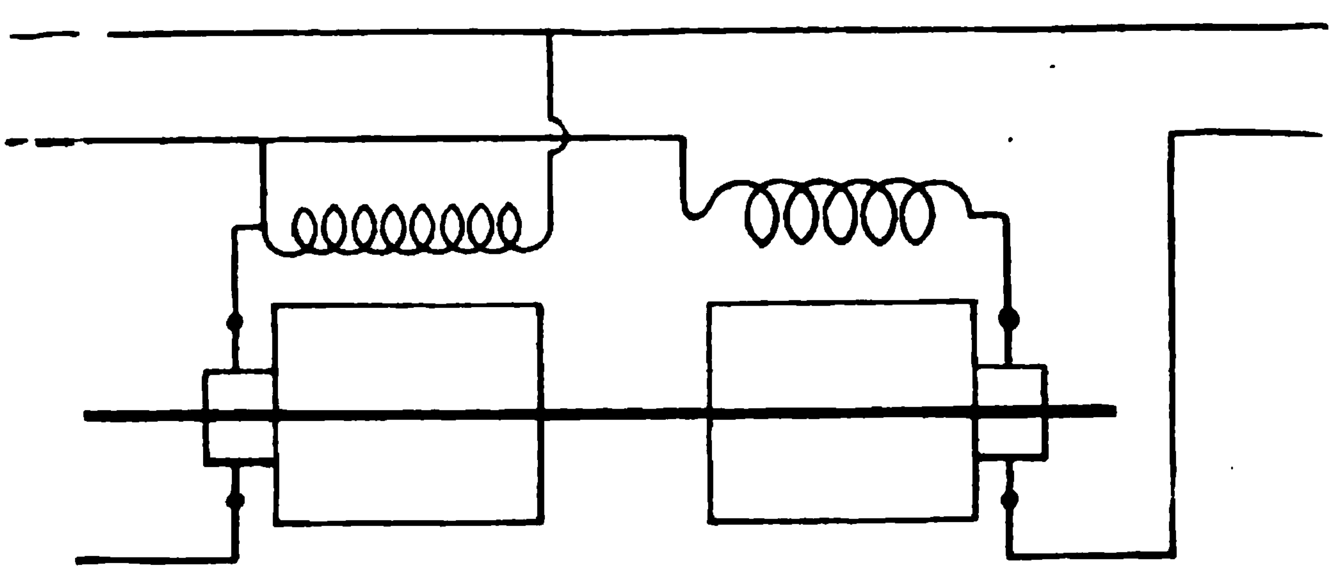


FIG. 173.

direction and driven as a motor, which would occur if the driving power of the motor were to fail from any cause; the speed would rise to such a value as to, very likely, wreck the machine. Therefore some means is usually provided to automatically cut out the booster in case of accident to the motor.

Long distance electric power transmission systems always employ very high tension, from 10,000 to 60,000 volts, and are either two-phase or three-phase, although the monocyclic system can be used. For two-phase four wires are generally used, though it can be operated with three; three-phase systems, as a rule, use three wires.

The high voltages are not produced directly by the generators, but are furnished by the secondaries of step-up transformers feeding into the transmission line. At the delivery end, the high tension current is taken to the primaries of step-down transformers, which lower the voltage to the value determined upon for the local primary distributing system. For lighting service the current is distributed just as in a single-phase system, that is, the transformer primaries are connected across one of

the phases. For motor service two single-phase transformers are used on a two-phase system, or three on three-phase (one for each phase), their primaries being each connected across one of the phases. That is the usual method, although regular two or three-phase transformers can be obtained, one of them taking care of the several phases. The secondaries are taken to the

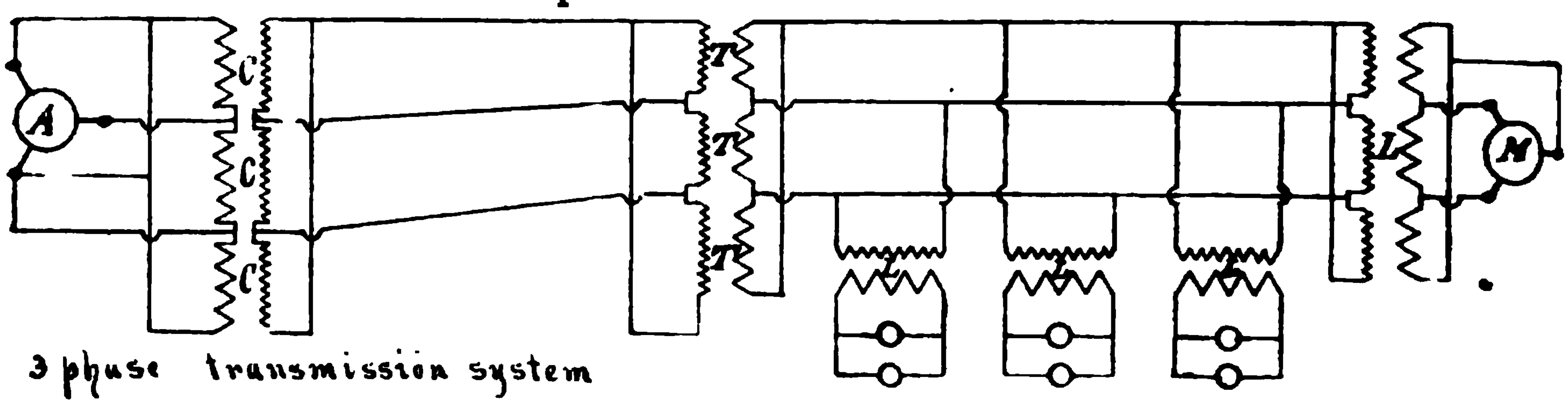


FIG. 174.

motors. Figure 174 is a diagram of a three-phase system, single-phase transformers being used at the delivery end. A is the alternator, C C C are the step-up transformers at the generating station, T T T are the step-down transformers at the transforming or distributing station or sub-station, and L L, etc.,

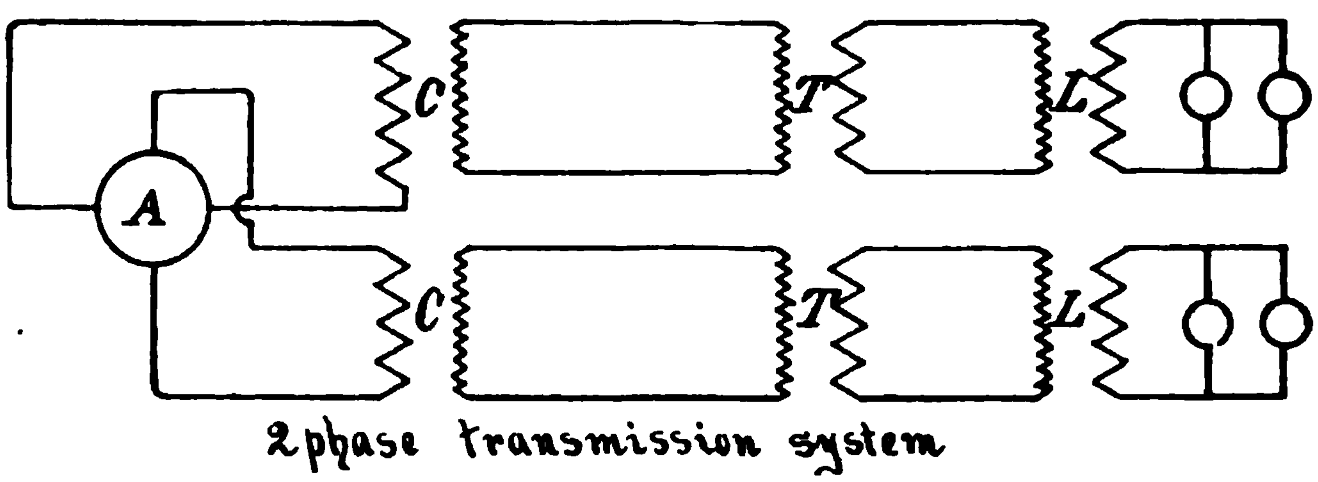


FIG. 175.

are the local transformers for the various consumers. Figure 175 shows a similar arrangement using two-phase transmission. Figure 176 shows a three-phase system using four-wire low-tension secondary distribution; the primaries are delta connected, although the Y connection can also be used if desired. The secondaries are Y connected and from the common juncture a fourth wire is run out. If the primary voltage is 2000 and the ratio of transformation is 10:1, the secondary voltage of any two of the three main wires is 200, and that between the fourth wire and either of the three main wires equals

$$\frac{200}{\sqrt{3}} \text{ or } \frac{200}{1.732} = 115.4.$$

Therefore, incandescent lamps can be connected between the fourth wire (which corresponds to the neutral of an ordinary three-wire system) and either of the main wires. As long as the load is equally distributed the neutral carries no current; it should, however, be of the same size as the other wires, unless motors are also fed from the same transformers, in which case

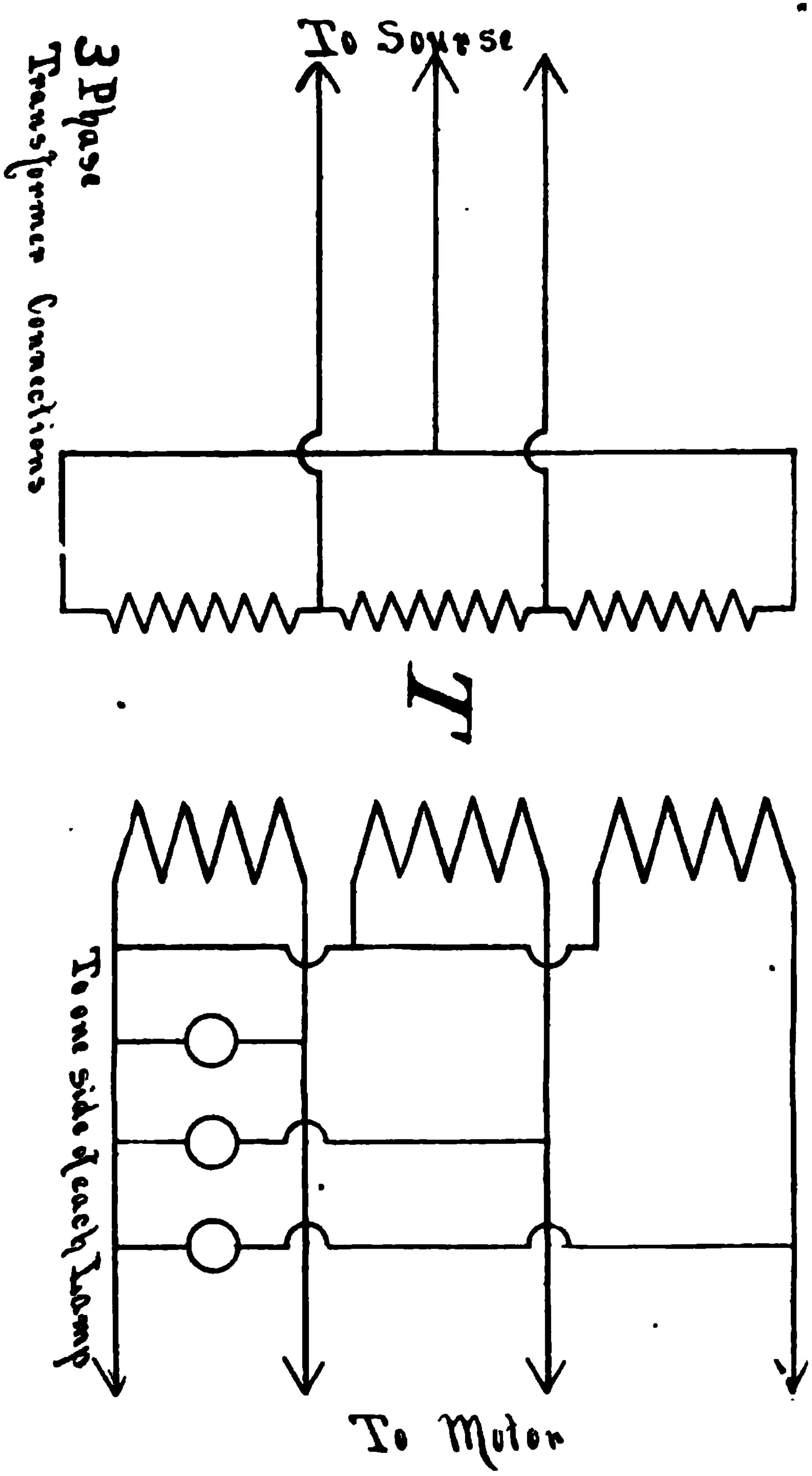


FIG. 176.

it may be considerably smaller, the extent of the difference being proportional to the motor load. Motors are connected to the three main (200-volt) wires. Only one-third as much copper is required in this system as in a two-wire single-phase or four-wire two-phase system at any given load, voltage and line loss.

In calculating the size of the wires use the voltage between the main wires.

Figure 177 shows the connection of three single-phase transformers, both primary and secondary delta connected, supplying current to a three-phase induction motor, and Figure 178 shows the use of only two transformers for the same purpose, proportionally larger ones being used, however.

Figure 179 shows a two-phase generator supplying a three-phase line, three-phase current being obtained by special transformers.

Figure 180 shows the connections for a monocyclic system for two-wire motor and three-wire lighting circuits. Both primary and secondary windings have a tap brought out from their center. This tap from the primary is connected to the teazer or power wire through the primary of an auxiliary transformer, and the outer ends go to the line from generator or step-down transformer, as the case may be. The secondary wires constitute a three-wire system, the tap from the center of the secondary winding being the neutral. Motors are connected to the two outer wires, and the teazer connection is obtained from the neutral through the secondary of the auxiliary or supplementary transformer mentioned above. This transformer should have a K. W. rating of about half the rated H.-P. capacity of the motor. If the motor load on such a system be large, compared to the lighting load, the lamps will fluctuate considerably, owing to the variation of the drop in the transformers, caused by fluctuations of the motor load.

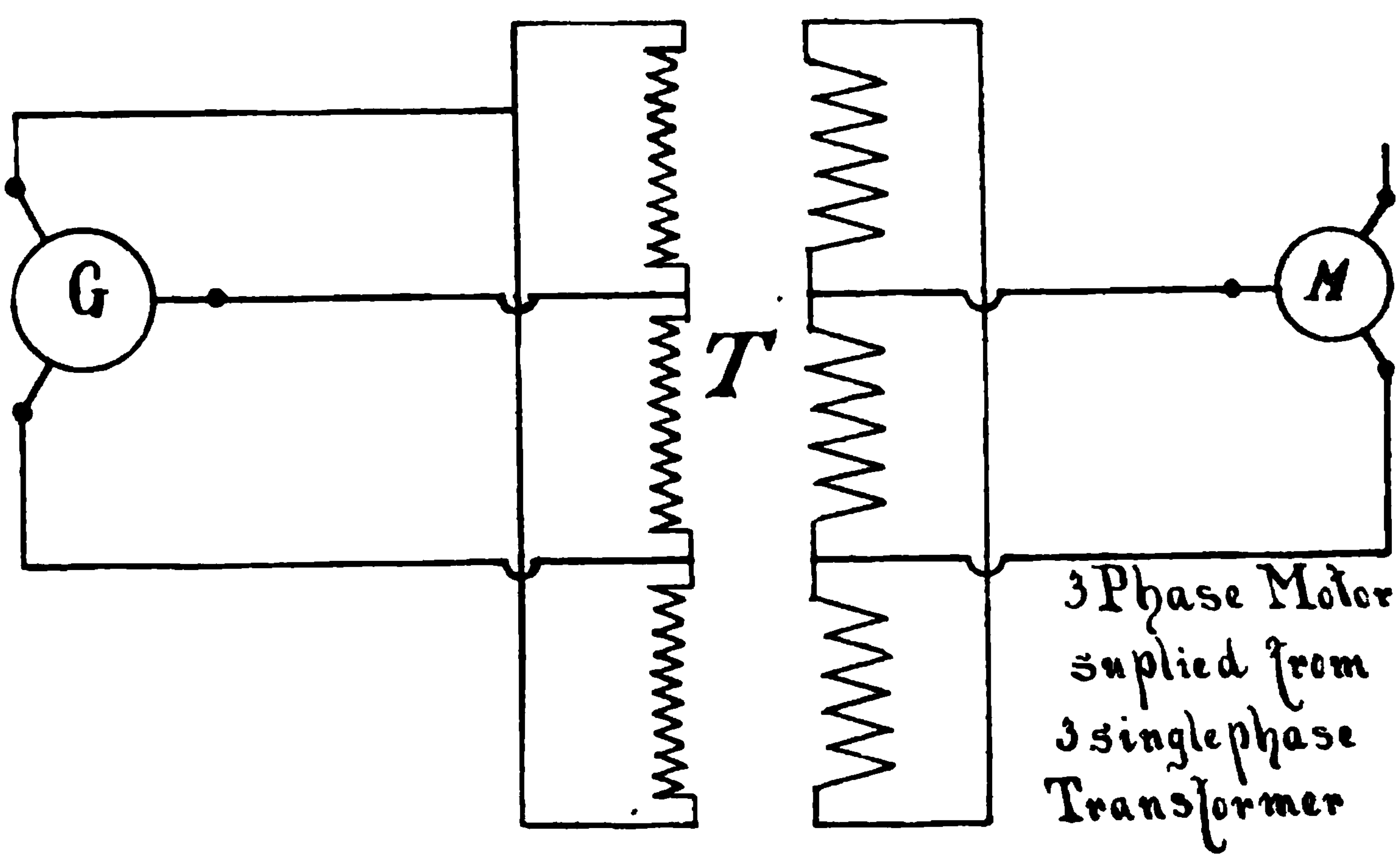


FIG. 177.

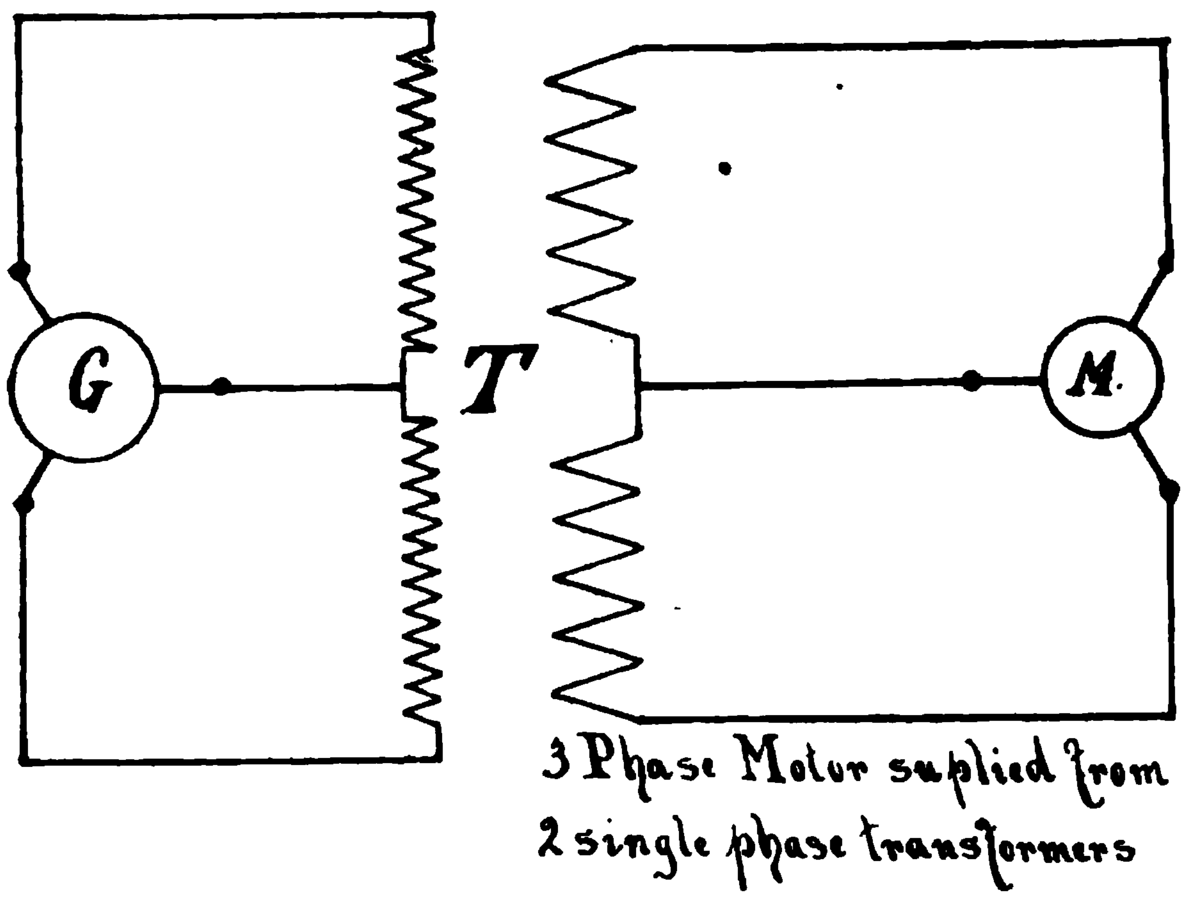


FIG. 178.

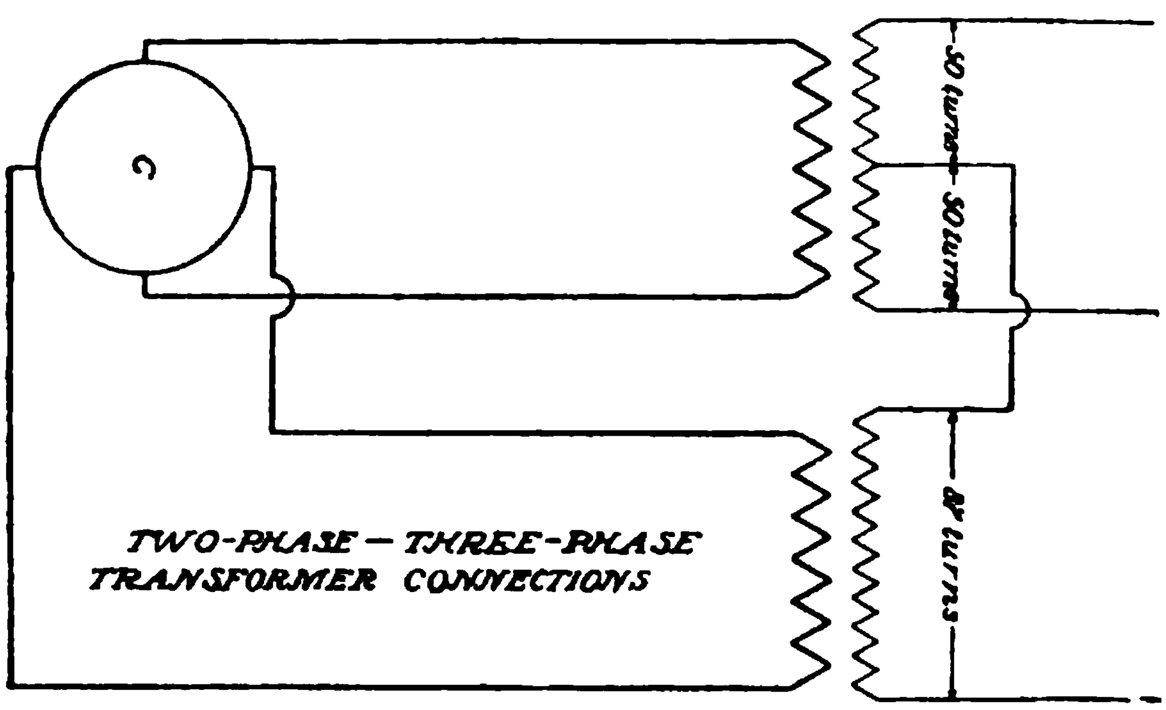


FIG. 179.

Sometimes it is desired to use d. c. current for the operation of a street railway or power system without putting in a d. c. generator. In such a case a rotary converter is installed, its a. c. end being fed from the secondaries of a special static transformer, and the d. c. feeders being connected to the d. c. end of the converter. The use of the special static transformer is to supply the a. c. end of the converter with the proper voltage, as the d. c. voltage is always in a given proportion to that of

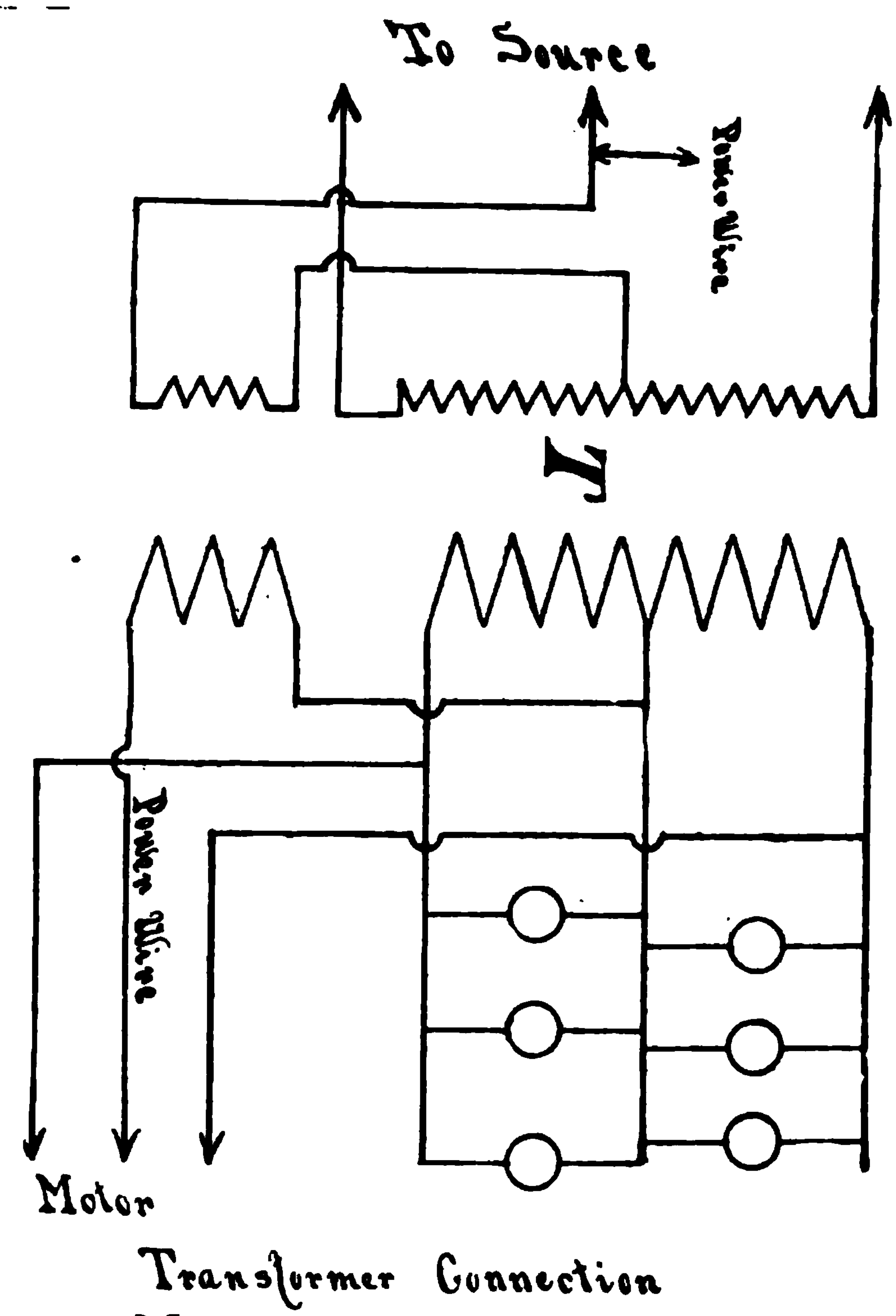


FIG. 180.

the a. c. end, regardless of the load, as explained in the chapter on rotary converters; Figure 181 shows the method of connecting a three-phase converter to a street railway system. Where two converters are used it is not good practice to operate both from the same transformer secondaries, as the commutation is thereby affected by local currents in the rotaries, and sparking at the commutator results. There should be a separate set of secondaries for each rotary, or, better still, an individual trans-

former for each. Both arrangements are shown diagramatically in Figures 182 and 183, respectively.

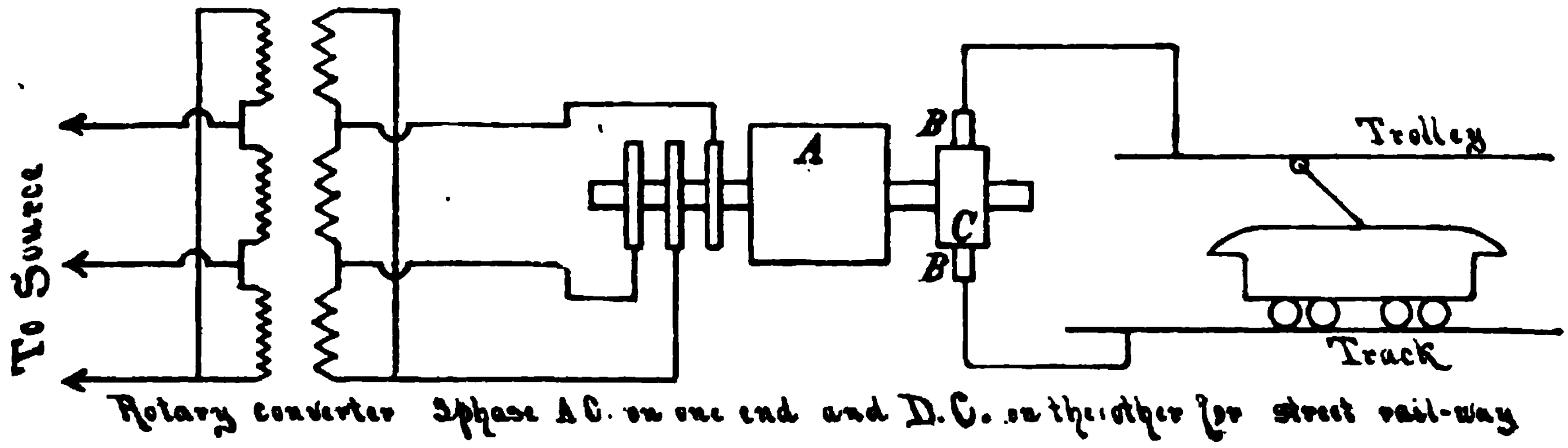


FIG. 181.

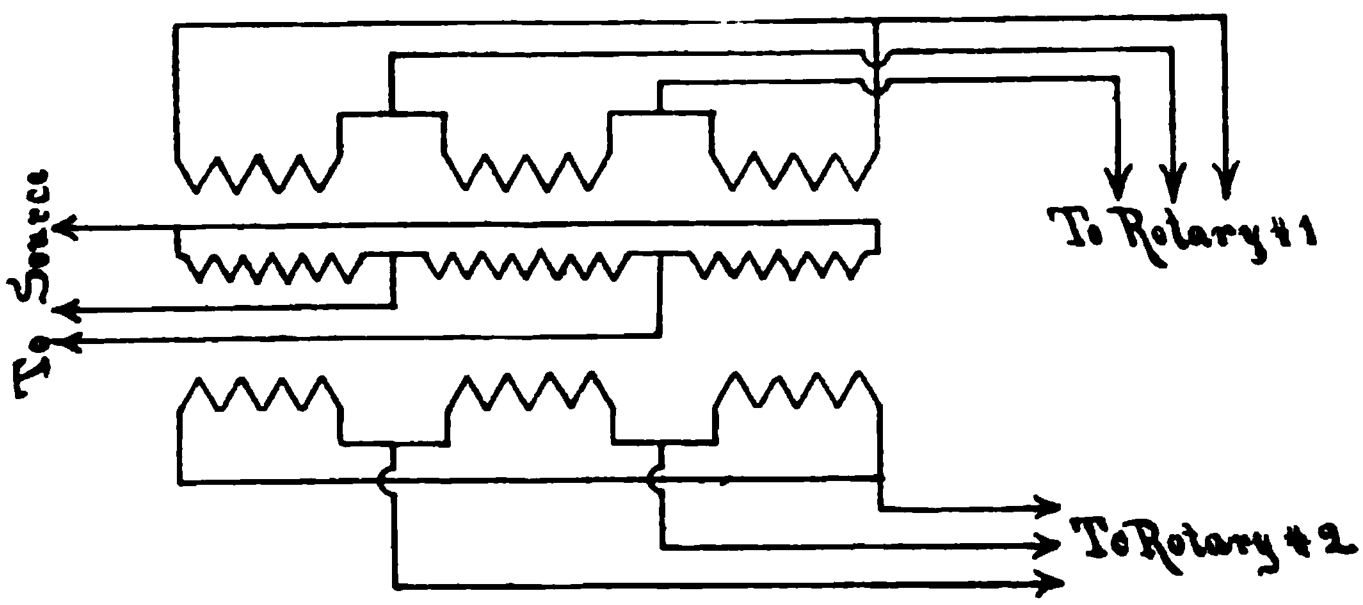


FIG. 182.

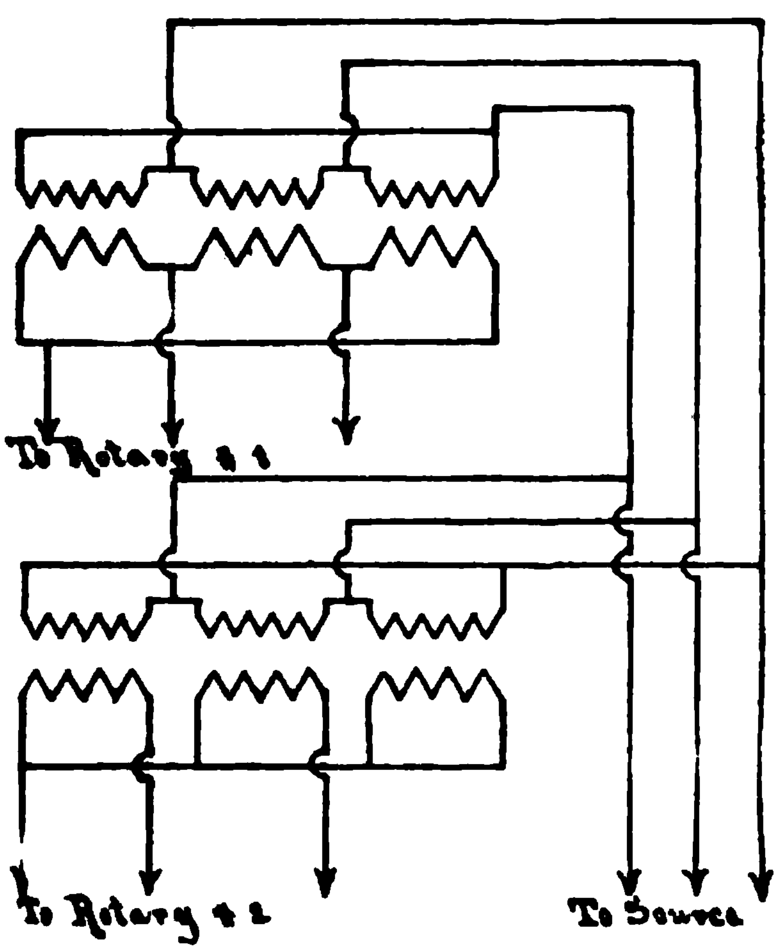


FIG. 183.

CHAPTER XXIII.

WIRING CALCULATIONS.

To find the size wire required to transmit a given number of amperes a given distance, and at a given loss, multiply twice the distance (since there are two wires) by the amperes, and that product by 10.8; divide this last product by the number of volts of permissible drop; if the latter is stated in per cent. of the total voltage reduce the per cent to volts. The quotient is the area of the wire in circular mils. By referring to a wire table one can tell what gauge number of wire this area corresponds to. If it comes between two sizes the larger size should be used, unless the smaller one is only slightly below the required size. Thus, what size wire is required to carry 60 amperes 100 feet 5 volts drop?

Solution:

$$\frac{2 \times 100 \times 60 \times 10.8}{5} = \frac{129600}{5} = 25920 \text{ C. M.}$$

By referring to a wire table we see that No. 6 is the size to be used. If we want to find the drop in a circuit when the size of the wire, the current, and the distance are given, we multiply the current by twice the distance and that product by 10.8, and divide the last product by the area in C. M. of the wire; the result is the drop in volts. A No. 10 wire carries 20 amperes 50 feet; what is the drop?

Solution: No. 10 has an area of 10380 C. M., hence:

$$\frac{2 \times 50 \times 20 \times 10.8}{10380} = \frac{21600}{10380} = 2.08 \text{ volts.}$$

This is for circuits on which the entire load is at the end. When the load is uniformly distributed over the entire length the method is the same, except that only the single distance is figured, or, if the double distance is taken, 5.4 is the constant used instead of 10.8. To figure the size of wire to use for a three-wire system, figure it the same as if it were two-wire, and divide the result by four, as the three-wire system takes only one-fourth the copper that a two-wire system takes, all things being equal.

This is accurate for all d. c. systems, whether for outside or inside construction; also for a. c. installations where the wires used are small and the runs not too long. On a. c. lines the reactance increases the apparent resistance of the line so that if only the ohmic resistance were figured the line loss would be greater than what is permissible.

The effects on a. c. lines are capacity, skin effect, self and mutual induction. By skin effect is meant the property of an alternating current of apparently flowing only on the outer surface of a conductor, which property retards the flow of current as the entire area of the wire is not made use of. This effect need not be taken into consideration on small and medium sized wires; it is only in wires of large diameter in which it reaches an appreciable magnitude. Below is a table published by Mr. Emmet, giving the various factors by which the ohmic resistance must be multiplied to get the resistance of a wire to an alternating current. To find the proper factor multiply the frequency (cycles per second) by the area of the wire in C. M.; the number in the table opposite that value is the factor. Thus, for a wire of 500,000 C. M., and a frequency of 60 cycles, we have: $500{,}000 \times 60 = 30{,}000{,}000$; opposite which is the factor 1.03. The resistance of a wire having an area of 500,000 C. M. is, approximately, .02 ohms; multiplying this by the factor, we have: $.02 \times 1.03 = .0206$ ohms.

TABLE.

Product of circular mils by cycles per second.	*Factor.*
10000000	1.00
20000000	1.01
30000000	1.03
40000000	1.05
50000000	1.08
60000000	1.10
70000000	1.13
80000000	1.17
90000000	1.20
100000000	1.25
125000000	1.34
150000000	1.43

Capacity is due to the condenser action of the lines carrying alternating currents. The wires form the two plates of a condenser and the insulation between them is the dielectric. They are alternately charged and discharged by the constant reversals of the current, being charged as the e. m. f. rises, and discharged when the e. m. f. falls. Thus capacity helps to overcome the e. m. f. of self induction of the line, and by connecting a condenser of sufficient size across the line, in multiple, can be made to neutralize it entirely.

In every a. c. circuit there is an e. m. f. of self-induction produced by the reversals of the current. This e. m. f. of self-

induction is opposed to the line or impressed e. m. f., therefore increases the apparent resistance of the circuit. The sum of this and the ohmic resistance being called the impedance. The latter should be used in applying Ohm's law to a. c. wiring calculations for large installations. Below is a table, published by Mr. Foster, giving impedence factors by which the ohmic drop of a line should be multiplied to find the actual drop. The first five wire sizes are diameters in inches; the balance are B. & S. gauge. Various spacing distances are given, because the effect of self-induction increases with the distance between wires; also, the higher the frequency the greater the self-induction. The table is computed for a frequency of 100. For other frequencies the impedance factor can be found by multiplying the square of the frequency by the multiplier of the given size wire and of the given distance between the two wires, and extracting the square root of the sum of this product, plus one; thus, suppose we have a line of No. 0000 wire, the two wires being 12 inches from center to center, and the frequency being 60. The multiplier for No. 0000 wire at 12-inch spacing is given in the table as .001129; the square of the frequency is 60×60=3600. Multiplying: 3600×.001129=4.0644. We now extract the square root of the sum of that product, plus one, which is:
$\sqrt{4.0644 + 1} = \sqrt{5.0644} = 2.25$.

TABLE F.

IMPEDANCE FACTORS AND MULTIPLIERS FOR A FREQUENCY OF 100 CYCLES PER SECOND.

Diam. Gauge No.								
2"	30.813	.994844	41.263	.170170	51.727	.26737	62.171	.386420
1½"	19 809	.039 42	25 692	.065905	31.574	.099596	37.459	.140223
1"	10.362	.010636	12.919	.016683	15.573	.024151	18.182	.032957
¾"	6.4873	.004108	7.94[illegible]5	.006212	9.4039	.008745	10.869	.011712
½°	3 3829	.001044	4 0118	.001509	4.6474	.002059	5.2874	.002696
0000	2.9793	.000787	3.5060	.001129	4.0400	.001532	4.5787	.001996
000	2.5004	.000525	2.9078	.000746	3.3225	.001000	3.7426	.001301
00	2.1227	.000351	2.4341	.000492	2.7528	.000658	3.0794	.000848
0	1.8316	.000235	2.0679	.000328	2.3130	.000435	2.5642	.000558
1	1.6021	.000157	1.7778	.000216	1.9622	,000284	2.1531	.000363
2	1.4306	.000105	1.5592	.000143	1.6958	.000187	1.8386	.000238
3	1.3024	.000069	1 3944	.000094	1.4935	.000123	1.5982	.000155
4	1.2092	.000046	1.2737	.000062	1.3439	.000081	1.4190	.000101
5	1.1428	.000031	1.1868	.000041	1.2357	.000053	1.2884	.000066
6	1.0968	.000020	1 1266	.000027	1.1598	000035	1.1960	.0000438
7	1.0649	.0000134	1.0847	.0000176	1.1070	.0000225	1.1313	.0000277
8	1.0440	.0000089	1.0573	.0000118	1.0722	.0000140	1.0886	.000018
9	1.0288	.0000058	1.0373	.0000076	1.0470	.0000096	1.0576	.0000119
10	1.0196	.0000039	1.0234	.0000049	1.0309	.0000063	1.0377	.000007

To find the factor for any frequency:

(Multiplier × frequency squared) plus one = the required factor.

It will be seen from the table that the impedance of the smaller wire sizes, even with a frequency as high as 100, is so small that it can be neglected, except for very long circuits.

Another inductive effect on a. c. lines is mutual induction, which occurs when two a. c. circuits are run near, and parallel to one another. One acts as secondary to the other, which causes an increase or a decrease in its drop (depending on whether the induced e. m. f. is acting with or against the line e. m. f.) if the alternations of the two currents are alike; if they differ, the effect is to cause a fluctuation in the line voltage.

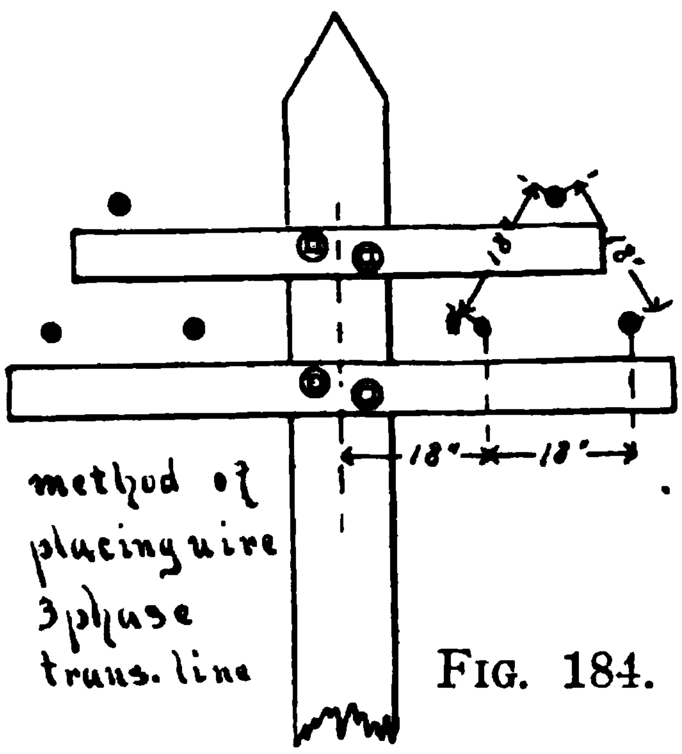


FIG. 184.

The effect can be gotten rid of by placing the wires so that induction in one portion of the line shall act in opposition to that in the other, thereby neutralizing one another. Where only a moderate voltage is used, and the distance is only a few miles it will only be necessary to make the distance between wires of a circuit small in comparison to the distance between the circuits. On long lines and where the voltage is high the lines should be transposed, that is, the different wires should have their relative positions interchanged, which can be done by one of the following methods. Figure 184 shows an arrangement in which

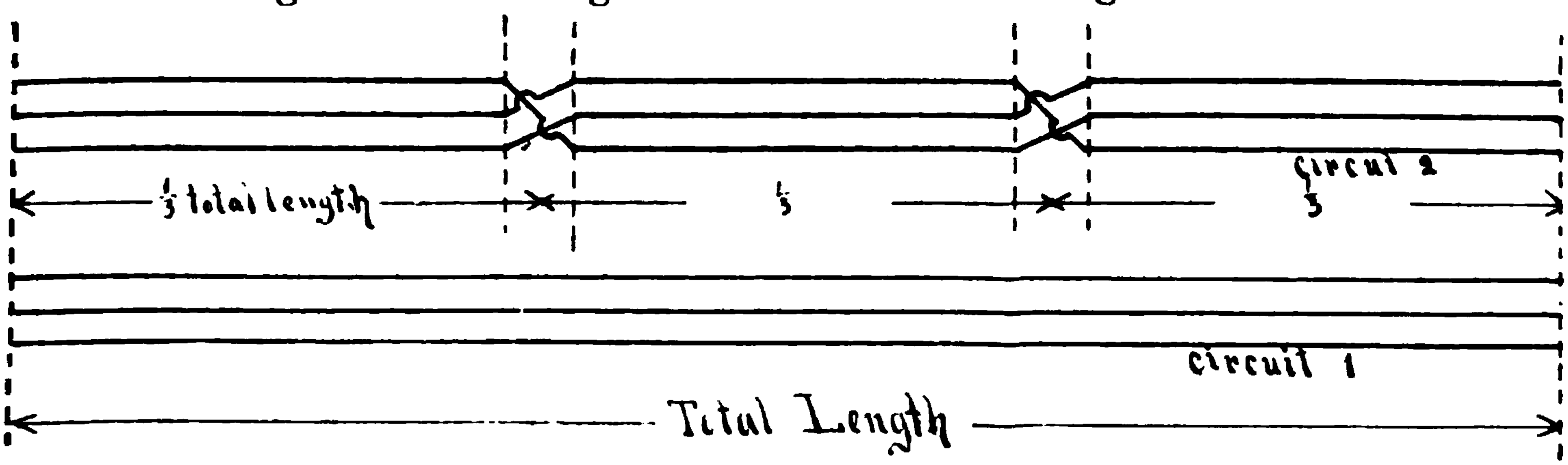
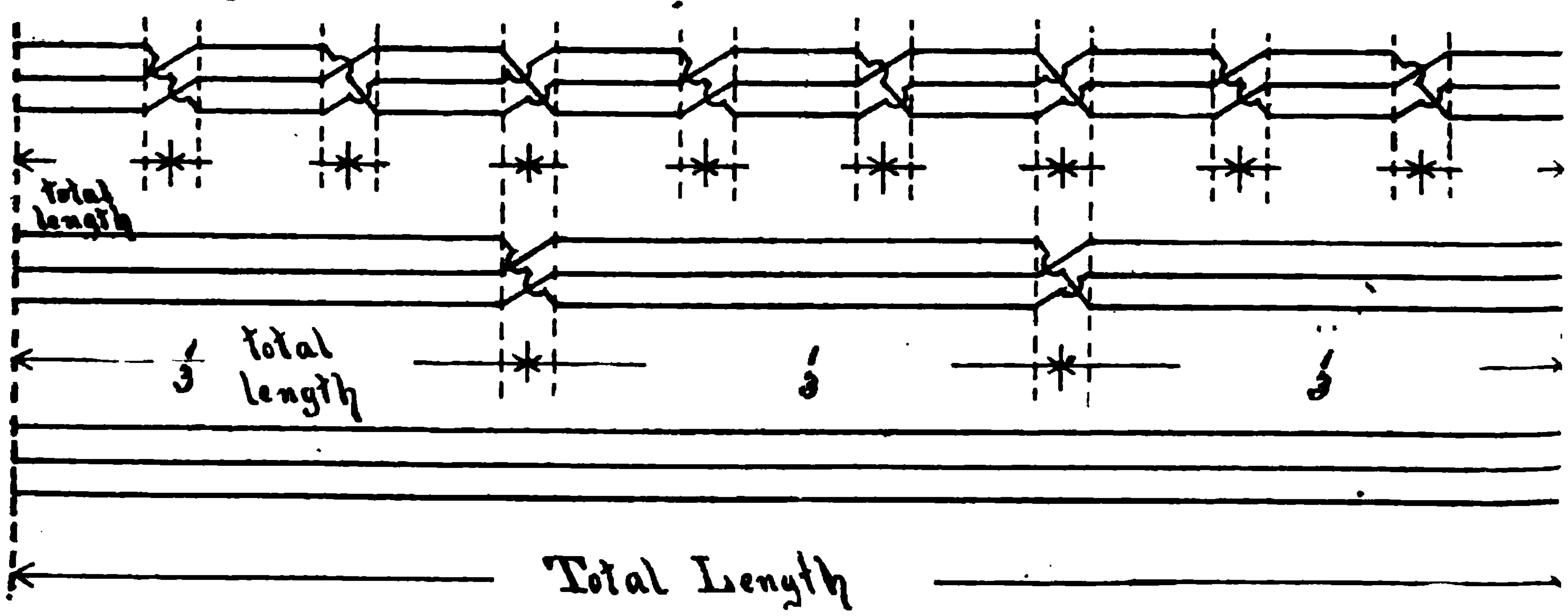


FIG. 185.

there is a three-phase circuit, so arranged that the three wires form an equilateral triangle 18 inches long on each side, this is standard distance for voltages not exceeding 12,000; no transpositions are needed, no matter how great the load, as long as there is but one circuit. When there are two or more, and

a considerable difference of phase exists between them they should be transposed, as shown in Figure 185, which shows two circuits; one is divided into three equal parts, the different parts being so cross connected that the relative position of each wire to the other circuit is the same for an equal distance. Thus, we see that each wire of circuit No. 2 has one-third of its length next to the other circuit, one-third farthest from it and

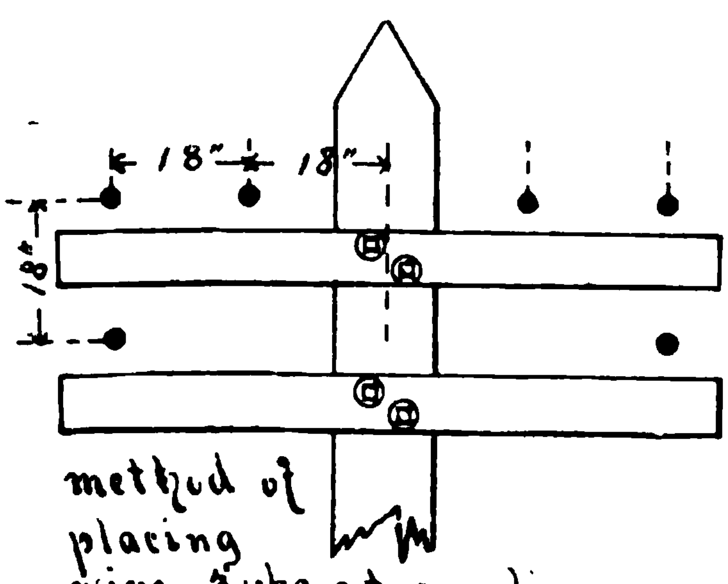


Diag. of Line Transposition

FIG. 186.

the remainder of its length in the midway position. Figure 186 shows the arrangement for an additional circuit, it being divided into three times the number of sections of circuit No. 2; that gives three sub-sections in circuit No. 3 in the length of one section of No. 2. Each of these sub-sections is then transposed, as shown, making their relations to each section of No. 2 precisely the same as the relation of the entire length of No. 2 is to the full length of No. 1.

For moderate sized installations, working below 12,000 volts,



method of placing wire 3 phase trans. line

FIG. 187.

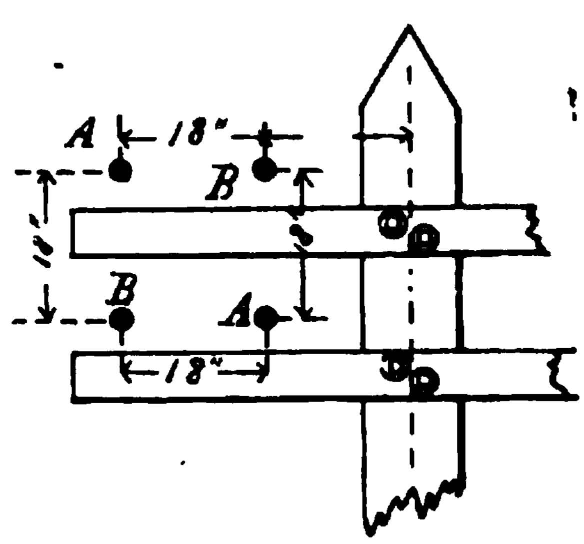


FIG. 188.

an arrangement is shown in Figure 187, in which no transpositions are needed. The line is not perfectly balanced at all loads, but is near enough so to render transpositions unnecessary.

If the three wires of a circuit are all side by side on the same level, they must be transposed to overcome the inductive effect on heavy load; use the same plan as in circuit No. 2 of the preceding figure. Should there be branch circuits taken from the main line and similarly run, they should also be transposed in like manner. In such a case the main line must be transposed between the branch and each end; also between branches, if there are two or more. Thus the length of line between generator and first tap has three equal sections, as has also the length between the farthest tap from generator and delivery end, and the lengths between the branches.

Figure 188 shows an arrangement for a four-wire two-phase line which is balanced without the use of transpositions. The vertical distance between wires is made equal to the horizontal distance, thus placing each wire in one corner of a square; wires diagonally opposite being one phase, as A A are the wires of phase A, and B B are the wires of phase B.

Where both phases are on one cross-arm, if the two phases be considerable farther apart than the two wires of one phase, no appreciable interference will take place on moderate loads. Should any bad effect be noticed, transpose one phase in the middle of its length, as shown in Figure 189, which will remedy the trouble.

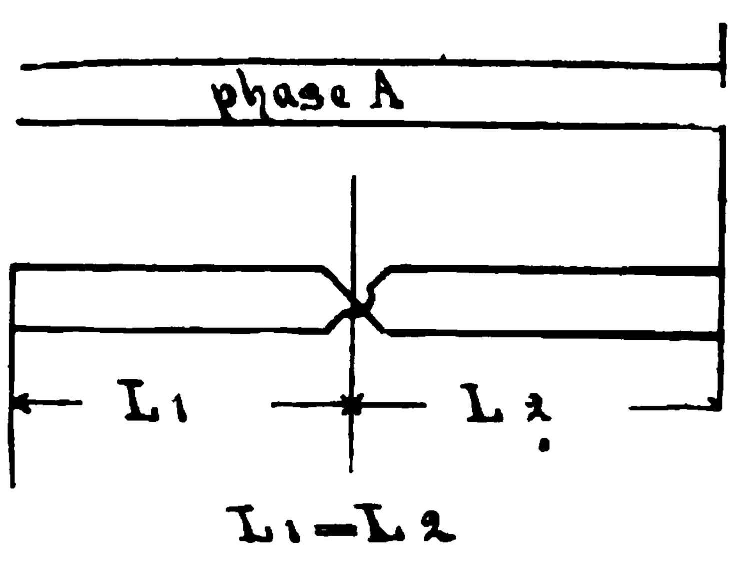


FIG. 189.

CHAPTER XXIV.

INSTALLATION, OPERATION AND REPAIR OF ELECTRICAL APPARATUS.

Whenever possible, electrical apparatus should be installed in a clean, well-ventilated place that is free from moisture. In places where considerable dust and dirt is flying around motors or generators should be in a room by themselves or should be inclosed.

See that every machine installed is firmly secured to its support or foundation; they should be mounted on wooden insulating frames which have been filled with oil to prevent their absorption of moisture. Very large, and, as a rule, all direct-connected machines are set directly on their foundations.

When assembling a machine see that the joints of the magnetic circuit are free from dirt, rust or anything else which would tend to impair the quality of the contact. See that the journals and bearings are smooth and clean and that the oil-rings turn freely; fill oil-wells to the proper level with a good quality of lubricating oil. Turn armature by hand to make sure that bearings are not too tight and that there is nothing to prevent the armature from turning freely. When hoisting up any portion of a machine arrange your slings so that in no case will the weight come onto the winding and never place a sling around the commutator of an armature if you can possibly avoid it; some commutators will stand it, but most of them will not. Pass the sling around the shaft and use a "spreader" to keep the sling from chafing the winding, a piece of 2" x 4" studding notched at each end answers the purpose very well. Its length should be equal to or a trifle greater than the combined width of armature and commutator, see Figure 190. Also be careful not to bump the commutator against any projecting portion of the machine,

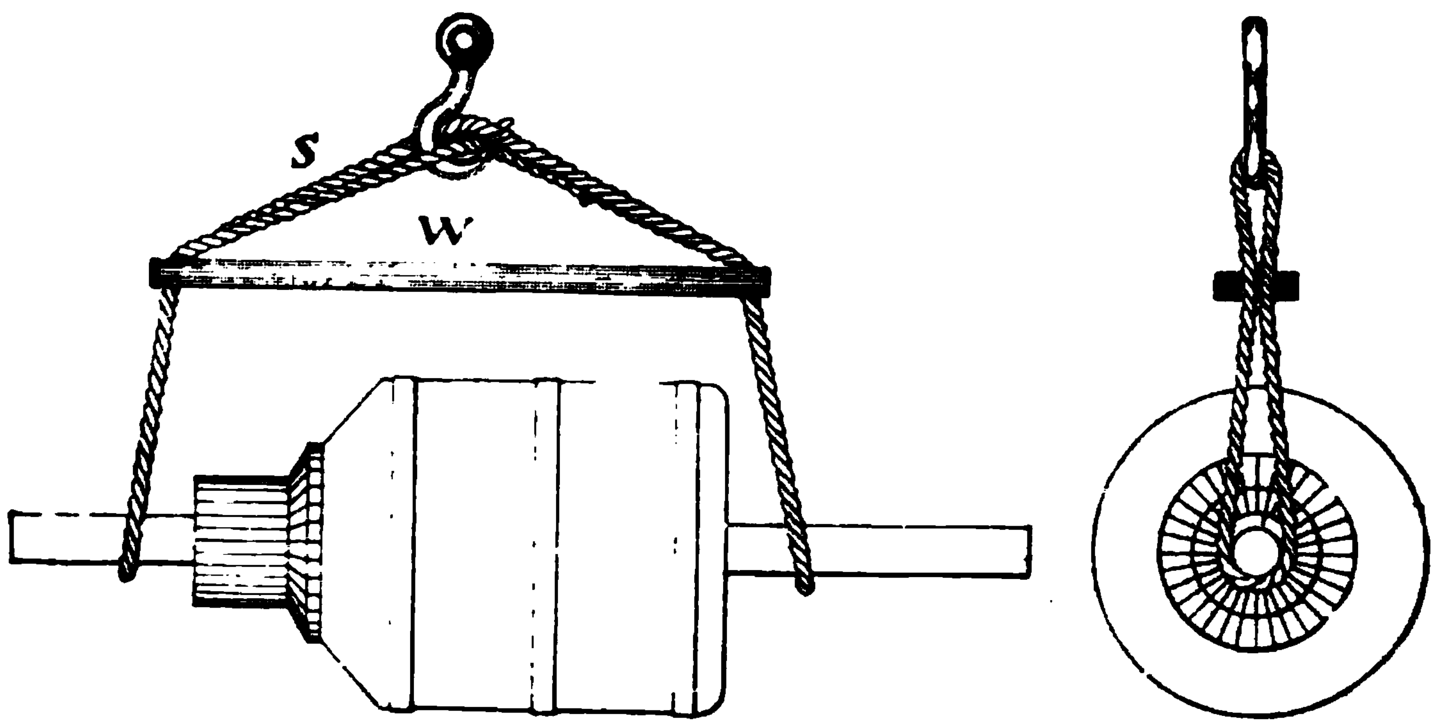


FIG. 190.

or a low bar may be the result, which would cause sparking and chattering at the brushes when the machine is in operation. All electrical connections should be clean and firmly made, be sure they are right before you turn on the current.

Belted generators and motors are mounted on bases that permit sliding the machine a considerable distance by means of screws attached thereto; by this means one is enabled to regulate the tension of the belt. Measurements for new belts should be taken with the shortest distance between the two pulleys; this is necessary because all new belts stretch considerably. Do not use laced belts; use endless belts, that is the kind having cemented joints. Run them as loose as you can; just tighten them enough to prevent slipping, running belts tight causes hot bearings, with all their attendant annoyances; the greater the distance between the two pulleys the looser the belt can be run. This distance should not be less than three and one-half to four times the diameter of the larger pulley; the tight side of the belt should be on the bottom. Use a good grade of belting; cheap belting is costly economy.

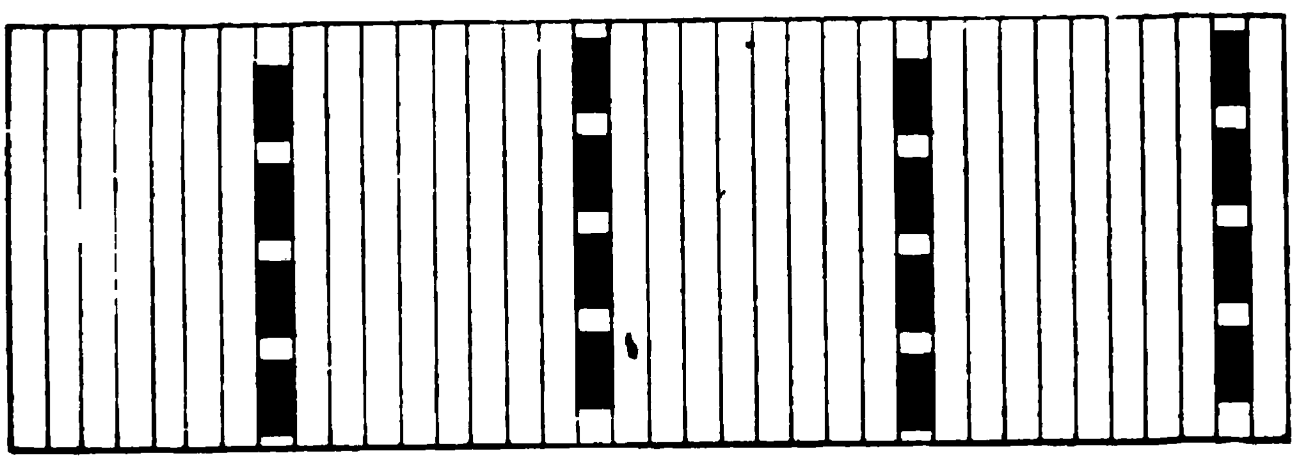


FIG. 191.

See that the commutator is true, smooth and clean; place brush-holders and brushes in their proper position. In a bi-polar machine the brushes should be diametrically opposite, in a multi-polar machine they are 90°, 60°, 45° or 36° apart, depending on whether the machine is four, six, eight or ten-pole. To find whether all the brushes are at equal distance apart, count the number of commutator segments between two neighboring brushes; when properly set the same number of segments should be between any neighboring set. When several brushes are mounted on one brush-holder stud, arrange the former so that the joints between those of one set come opposite the centers of the next set, as shown in Figure 191, which shows the circumference of a commutator flattened out, the dark blocks represent carbon brushes. Use a good quality moderately soft carbon free from hard spots and impurities; adjust the tension so that brushes make a firm contact with commutator, but do not

tighten them so much that they will "sing." When putting in new ones take a strip of sand-paper and insert it between brush and commutator, cutting side out, and draw it back and forth until the face of the brush conforms to the curvature of the commutator, thus insuring a good contact right from the start. Wipe the commutator occasionally, while the machine is running, with a piece of canvas, if bright streaks appear on the surface it is a sign that a brush is cutting, owing to a hard spot in it, or some gritty substance on its face. Remove the brush that is causing the trouble and clean it, sometimes cutting can be stopped by the application of a bit of oil. A drop or two should be rubbed on a piece of clean cloth or canvas and the cloth applied to the commutator. Should a commutator become covered with a brown gloss do not think it is dirty and needs sand-papering, that gloss or mahogany polish is what is striven for by dynamo tenders, as a commutator that has it is in the pink of condition. Sand-paper should be used sparingly, if at all, and emery cloth or paper should never be used; when a commutator is cutting or has become rough, sand-paper is a good thing, do not use any coarser than No. 1. After having sand-papered a commutator it is well to remove the brushes and clean them, as small particles of copper are likely to gather under them and cause cutting. Use carbon brushes whenever practicable, they do not wear the commutator so much as copper brushes and in case there is sparking most of the burning will be confined to the brushes; further, they are cheaper than copper brushes. Their resistance is somewhat higher, however, and for that reason machines whose voltage is less than 100-110 are equipped with copper brushes. Carbon brushes are usually copper plated, which materially lessens their resistance.

The oil in the oil wells should be drawn off and clean oil put in about once a month; the oil removed can be filtered and used again. Use what is known as dynamo oil and remember that a good oil is cheaper than a poor oil in the long run, although its first cost may be greater.

The bearings of any piece of machinery will warm up when the machine is running and electrical apparatus is no exception. As long, however, as the hand does not feel uncomfortably warm when placed firmly on a bearing for 15 or 20 seconds there is no cause for anxiety. Moreover, if a motor or generator has been running for several hours, sometimes even days, under considerable load the entire machine will very likely be pretty warm, possibly even hot. In such a case, should the bearings be warmer than the hand can bear it does not follow that there is anything wrong with them. As the entire machine is hot the heat will be transmitted to the bearings also, and the attend-

ant should take that into consideration; the bearings may, although feeling quite hot, nevertheless be running comparatively cool. The difference between their temperature and that of the machine is, in such a case, the measure of the heat due to bearing friction; under such conditions it is advisable to use a somewhat heavier oil than the regular dynamo oil.

No directions will be given here for connecting up the different types of apparatus, as all that has been fully covered in preceding chapters. Neither will the repair of machines be gone into at length, as it would be an almost endless task to frame a rule for every case of trouble liable to occur. A study of the previous chapters will make any average man conversant with the principles upon which the operation of electrical apparatus depends. That knowledge will usually enable one to locate the cause of any case of trouble; when the cause is found the remedy is generally self-evident. A list of the most usual and frequent cases of trouble is given at the end of this chapter, however, intended principally for men of limited experience and as an aid in determining the probable cause of the bad behavior of a machine.

Before starting any machine see that it is clean and that all bolts, nuts and binding screws are tight; be sure that the brushes are in the proper position and have the right tension. A new machine should be run for several hours, or longer if possible, without load to make sure that the bearings are in good condition; see that the oil rings turn freely. If the machine is not equipped with self-oiling bearings see that the oil cups are full of oil and are feeding sufficiently, better feed oil freely at first and cut down the feed to the required amount gradually.

When starting a d. c. generator bring it up to speed with main and field switches open; as soon as full speed is attained see that all the resistance of the field rheostat is in circuit, close field switch and build up the voltage by manipulating the rheostat. Throw on the load by closing the main switch; a machine may be started up with the load on if desired and sometimes it is preferable to do so.

Arc machines are connected to the load at starting, but are brought up to speed with the brushes in the position of least action. When full speed has been attained they are gradually moved toward the point of maximum activity; since an idle series arc circuit has a low resistance, an arc machine, being series wound, builds up very quickly. As soon, however, as the current reaches normal strength the regulator automatically moves the brushes to the proper position, changing them thereafter to suit the variations of the load.

As already explained, arc machines are seldom connected

together, whereas constant-potential machines are frequently operated two or more together, either in series or in parallel, though the latter is the most common method. To be connected together in parallel it is essential that machines so connected have the same voltage, while to be connected in series they should have equal current or ampere capacity.

When connecting a generator in parallel with one already running bring the voltage of the new machine up to or a trifle higher than that of the one already running and then close the switch connecting the new machine to the bus-bars. In case a double-pole main switch is used with compound generators a single-pole switch is provided for the equalizer connections and this switch should be closed before closing the main switch. In shutting down one of the machines the equalizer switch should be opened after the main switch is opened. If you do not know the polarity of a new machine, as for instance, in the case of one just installed, make a polarity test to make sure of like polarities being connected together. This can be done with a lamp, or several lamps in series, if the voltage of the machines is more than that of one lamp. Connect one side of the lamp to one side of machine already running and the other side of the lamp to either side of the new machine; then connect the remaining terminals of the two machines together. If the lamp burns the positive terminal of one machine is connected to the negative terminal of the other, which is not the way they should be connected. If the lamp does not burn it indicates that it is connected to terminals of like polarity. If your test lamp remains dark on the first trial do not at once proceed to connect the two machines together. Test the lamp first, especially if you are using several of them in series, to make sure there is no open circuit in it.

There is a distinct advantage in using a triple-pole main switch where generators are operated in parallel, and using one pole, usually the middle one, for the equalizer, as by that means it is impossible to connect the two or more generators together without at the same time closing the equalizer switch. Where heavy currents have to be handled, however, the equalizer switch is generally mounted on a pedestal situated near each machine. This obviates the necessity for bringing a heavy and expensive conductor to the switchboard; the equalizer wire is usually made the same size as the main machine leads. When pedestal switches are used arrangements are made in some plants to control them electrically from the switchboard, in which case the attendant can open or close them by simply pressing a button or closing a small switch at the switchboard.

As soon as the new machine is in circuit, make it take over

its share of the load by cutting out the resistance of its field rheostat and cutting that of the other machine in.

When a machine that is running in parallel with another is to be shut down, work the entire load off the machine it is desired to shut down, by manipulating the field rheostat. As soon as the ammeter shows that the machine is furnishing no more current the main switch may safely be opened; then you may stop the machine, after which open the field switch. The main switch should in no case be opened while the machine it controls is feeding current into the bus-bars, as a bad flash would be the result, injuring, perhaps ruining the switch. The field switch should never be opened while the machine is still running, even though the main switch be already open. As the shunt field is connected to the machine between the latter and the main switch it follows that there will be current flowing in it until the machine comes to rest. Were the field circuit opened while current is flowing therein, the rise in voltage due to the e. m. f. of self-induction, commonly termed the "kick" of the field, might puncture the insulation of the armature. To eliminate the danger from this source the field switches on some switchboards are so arranged that a bank of incandescent lamps in series is connected across the terminals of the field coils when switch is open, the arrangement being such that the circuit through the lamps is closed before the connection between field and armature is broken, thereby providing a path for the inductive discharge. Figure 192 is a diagrammatic view of the arrangement.

Alternators are started very much the same way as d. c. machines. They have a rheostat in the field circuit of the exciter as well as in their own and either can be used to regulate the voltage, although it is a trifle more economical to keep the alternator field rheostat cut out entirely. They can be connected in parallel, provided their speed can be kept uniform. If composite wound they should have their series fields connected by an equalizer like compound d. c. machines; they work best when driven by water-wheels. When driven each by a separate engine the governors of the latter should be sluggish in their action, rather than quick-acting, to give the best results. Besides being of the same voltage, they must also be of the same frequency and must be in phase when connection is made. To enable one to tell when two alternators are in phase as well as in synchronism, synchronizing lamps and transformers are used, see Figure. 193. When the connections are as shown the lamps will be bright when the machines are in synchronism and phase, or, as it is called, in step. Reversing either the primaries or the secondaries of one of the transformers will have the effect that the lamp will be dark when the machines are in step. The author believes that it is

preferable to synchronize with lamps bright than to do so with lamps dark, as, with the latter method two machines may be coupled together when badly out of step if the lamp filament should be broken. The objection to synchronizing light lies in the difficulty of telling when the lamp has reached full candle power.

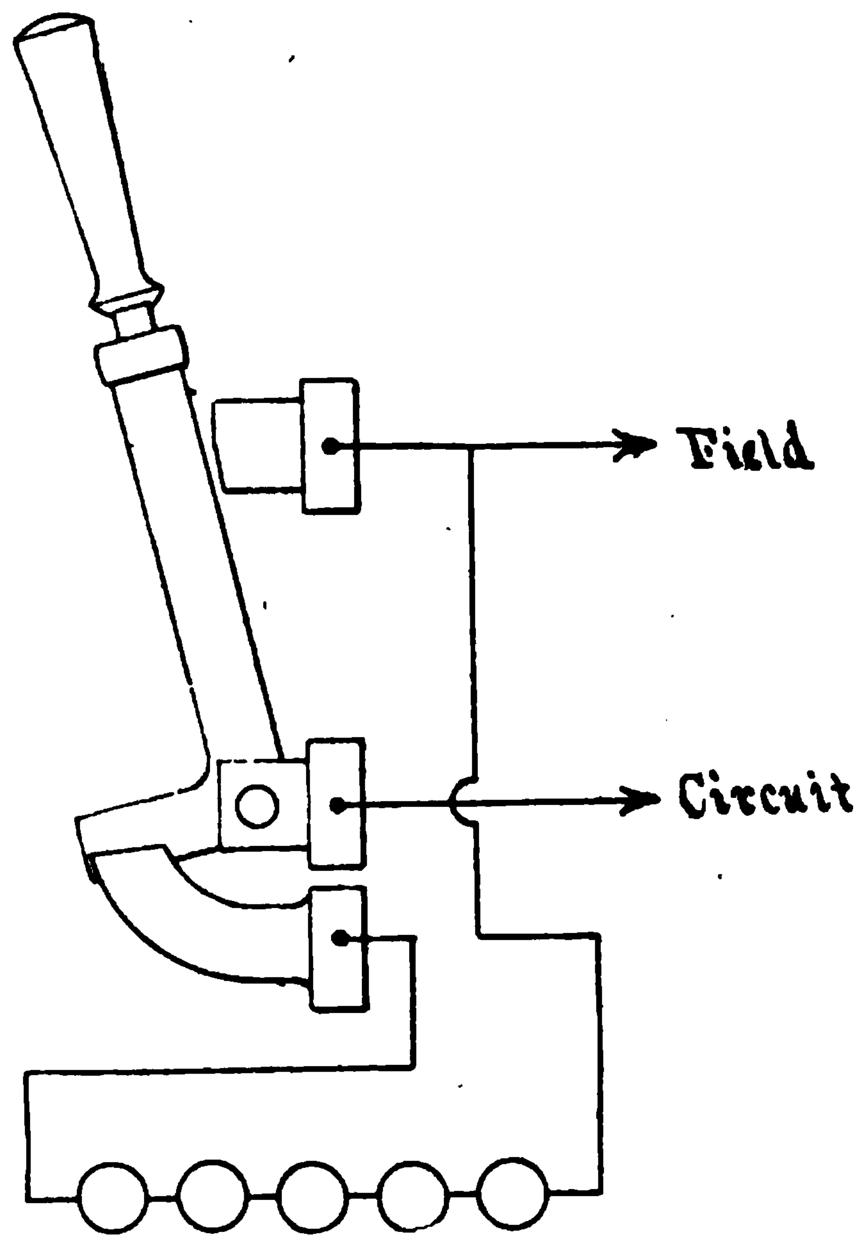


FIG. 192.

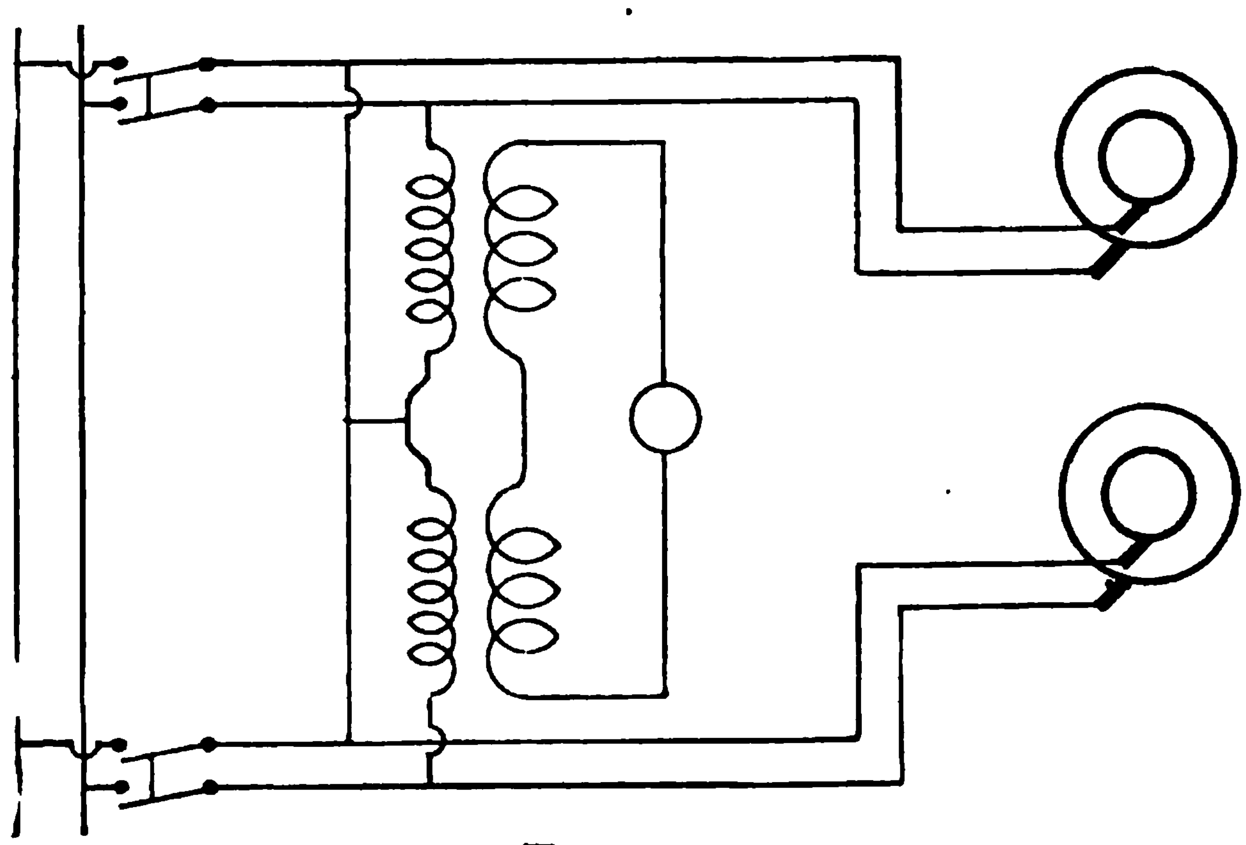


FIG. 193.

When connecting an idle machine to one already running, get the idle machine up to proper speed and raise its voltage to that of the other, close the synchronizing switch and when the synchronizing lamp is at full candle-power close the main switch, assuming that the synchronizing lamp is so connected that the burning of the lamp indicates synchronism.

The load can not be shifted from one alternator to another by a manipulation of the field rheostat, as in the case of d. c. machines; it can be done, however, by varying the driving force.

Polyphase alternators can also be connected in parallel, but must of course have the same number of phases as well as voltage and frequency. The synchronizing lamp and transformers are needed on only one of the phases of each machine, but they must be on the same relative phase of each.

Induction motors are usually started by means of an auto-transformer or compensator, which reduces the heavy starting current. After the motor has come up to speed the compensator is cut out and the motor connected directly to the line.

Synchronous motors, owing to their low starting torque, should be started without load. They are usually brought up to speed by an external source of power, in most cases by a small induction motor about one-tenth the capacity of the large motor. Before being connected to the line the motor should have reached synchronous speed and should be 180° out of phase with the line. Synchronizing lamps and transformers are used in determining this, the primaries of one of the latter being connected to the line and those of the other to the motor, the secondary connections being generally such that the lamp burns bright when synchronism and 180° phase difference exists. At this point the motor may be connected with the line; the load can then be put on and the small starting motor mechanically disconnected and shut down.

There is another method of starting synchronous motors, in case no external power is available. The field coils are each open circuited by break-up switches to minimize the danger of breaking down their insulation by the high voltage induced in them by the varying magnetic flux due to the alternating current in the armature before the latter reaches synchronism. The motor can be supplied with current either with or without a compensator; the machine then starts as an induction motor and when it has reached synchronism, or nearly so, the field circuit should be closed which brings the machine into step.

A rotary converter can be started in the same manner as a synchronous motor, either electrically or mechanically, using the same precautions in either case, but should be started with both a. c. and d. c. ends on open circuit when started mechanically.

Open the field circuit, bring machine up to speed, connect to the a. c. circuit first if that is live, which brings the machine into step, close the field circuit and close d. c. switch.

The best method, however, is to start them from the d. c. end, like a shunt motor. Keep a. c. end open, bring machine a little above synchronous speed, open the d. c. switch and also open the field circuits before closing a. c. switch if the a. c. system is live, then close a. c. switch bringing the machine into step, close the field circuit and connect the machine to the d. c. system.

Probably the most frequent trouble in dynamos and motors is sparking at the brushes; all d. c. machines are heirs to this ill. Composite wound alternators, being equipped with a commutator, also spark sometimes; in most of the d. c. series arc dynamos it can not be gotten rid of entirely. Constant potential machines, however, as built these days, will run absolutely sparkless under normal conditions.

Sparking causes heat and also wears out commutator and brushes rapidly; causes of sparking are as follows:

First. A very high resistance brush may spark owing to not making good contact with the commutator; such a brush is usually very hot and should be replaced with a new one.

Second. When a machine vibrates badly sparking generally results; increasing tension on brushes will reduce the latter, but the cause of the vibrattion should be eradicated, an unbalanced pulley or armature or unsteady foundation causes vibration.

Third. A high or a low bar may cause sparking, same can be felt by placing the end of a finger against commutator; turning down the commutator is the remedy.

Fourth. Open circuit in armature. Spark will be long, or if speed is high will appear as a fiery streak from brush to brush; insulation between two segments will appear burned upon examination. The break is in the coil connected to those two segments; break will generally be found in lead wire from coil to commutator, which can be quickly soldered. If break is inaccessible or out of sight, the damaged coil must be taken off and a new one put on; if machine cannot be spared so long just then, connect the two commutator segments together by a drop or two of solder; make permanent repairs soon thereafter as possible.

Fifth. Weak field may cause sparking. In such a case a generator will not generate full voltage and a motor runs above normal speed when only partially loaded. If fully loaded speed will drop and armature takes excessive current and therefore heats up considerably; a short circuit between some of the layers of a field coil would tend to weaken the field. Point of least sparking is shifted a considerable distance, owing to the greater distorting effect of the armature current on the weak field.

Sixth. A rough or eccentric commutator. Sand-paper some if moderately rough; if very rough or eccentric, or if it has high or low bars, turning it down is the only remedy. Use a diamond pointed tool and do not take a too heavy cut; when finished see that the tool did not drag particles of copper from one segment to another across the mica insulation. After sand-papering commutator, be sure to clean face of brushes, as if any sand or particles of copper get lodged on them they would cut the commutator.

Seventh. When brushes are not on the neutral line, sparking results; shift them, first in one way and then in the other. It may be that only one of them sparks; this indicates that they are not the right distance apart, readjust them.

Eighth. An overload. Reduce the load; the belt on an overloaded machine will be very tight on the tension side, and will generally slip; a slipping belt usually squeaks.

Heating is another common trouble and may be due to:

First. Excessive friction in bearing, generally a result of a lack of oil or some gritty substance getting into it; a tight belt may cause a hot bearing.

Second. Sparking will cause commutator and brushes to heat; apply foregoing remedies.

Third. Loose contacts or bad connections; tighten them up.

Fourth. A very hard or high-resistance brush will heat; take it out.

Fifth. Commutator that has been turned down repeatedly or has insufficient copper in its segments, will heat when machine is worked up to its full capacity and sometimes on less load; replace with a new one.

Sixth. A very hot commutator upon which carbon brushes are used will become covered with a dark dirty film which increases the heating and causes sparking. All you can do in that case until the cause of the heating has been removed is to wipe the commutator frequently.

Seventh. A field coil may heat owing to a portion of the winding being short circuited. In the case of a machine on street railway or other ground return service a "ground" (contact between conductor and frame of machine) would constitute a short circuit; part of the coil or coils would get considerably hotter than the rest.

Eighth. An overloaded machine will heat, as that causes an excessive flow of current.

Ninth. A short circuited armature coil causes heating, but will be confined to affected coil unless given time to spread; take off defective coil and put on new one.

Tenth. Moisture in an armature. Bake it in an oven for several hours or pass current of about 75 per cent normal strength through it until thoroughly dry.

Dynamo fails to generate. This is due generally to weak or an entire absence of residual magnetism, a reversed connection of the shunt winding or reversed direction of rotation; in either of the latter two cases reverse the shunt field connections. If residual magnetism is too weak, send a current through field from some external d. c. source.

Test field circuit for continuity.

A shunt machine will not build up if there is a heavy load connected or a short circuit on the line or in the armature; field coils may be opposed to each other. Pass current through them and test with a compass. If both poles in a bi-polar, or neighboring poles in a multi-polar machine attracts the same end of the needle one of them should be reversed.

A motor may fail to start, due to moving element binding somewhere or overload; try turning by hand; if not free to move, look for the trouble and remedy it.

There may be an open circuit in armature or field. In that case, no spark would appear on opening switch; test for continuity.

In a shunt motor armature, circuit may be closed, but field circuit open; test field for continuity. Or the field may be connected so that it is in series with the starting box; in such a case the motor would start quickly after most of resistance is cut out. Reverse the two wires in main binding posts (usually marked L and A) in rheostat; fields may oppose one another; test with compass.

If brushes are too far forward there will be a violent flashing as soon as the machine speeds up; if too far backward there will appear more of a burning rather than a flashing.

Short circuit in the armature will also prevent a motor from starting. Sometimes a motor with a short circuited armature will move just a trifle and stop; try moving it by hand, if it turns freely look or test for short circuit.

It should be borne in mind that in all the foregoing cases except the case of open armature circuit there will be a heavy current in armature, which will very likely manifest itself by blowing a fuse or tripping a circuit breaker and, incidentally, by heating the armature.

In conclusion, would say that, as with all other apparatus so also with electrical machines: "Eternal vigilance is the price of safety." Keep your machines and appliances as clean as possible; daily wiping may seem to you an unnecessary task, but believe me, it will pay you in the end.

COMPRESSED AIR

Compressed air as a means to transmit power from a central station to a distant point is, an established fact, and its practicability and economy no longer in doubt. It is a strong rival to electricity in the way of transmitting power and in some instances preferable to the latter, and in some cases indispensable.

Compressed air is used in mining, for running drills, pumping water, ventilating, etc. It is used in our great construction works, such as running machinery and pneumatic tubes. It is used for driving locomotives, street cars, automobiles, elevators, in fact there seems to be no limit to its use.

Air Compression Under Low Pressure.

In some cases an air pressure slightly higher than that which can be produced by ordinary bellows or blower fan is in demand, such as for operating pneumatic tubes, etc. A very useful device to obtain a pressure of about three pounds to the square inch is

Fig. 1.

shown in Figure 1, and is generally called a rotary pressure blower. It can be run any desired low speed and its measured volume is positive under a pressure of three pounds.

Air Compression Under High Pressure.

The greatest amount of work done by the use of compressed air is between 50 and 100 pounds to the square inch. In such cases we must employ an air compressor. A sectional view of an air compressor cylinder is represented in Figure 2, showing the piston, receiving and discharge valves and water jacket. In this construction two receiving valves are placed at each end, which is generally done in cylinders of large size, which would

otherwise require a valve of large area. The water jacket which is formed around the cylinder is supplied with water at one end, and is discharged at the other, continuously cooling the walls of the cylinder during its construction; otherwise the construction is that of a pump and acts as such.

FIG. 2.

Compression and Expansion.

It is well known that air when compressed increases in temperature and an expansion takes place during the act of compression, this depends a good deal on the size and speed of the machine and on the efficiency of the water jacket. This can best be made clear by studying the diagram, Figure 3. A B represents the adiabatic line or the work if there was no cooling done and the air would lose none of its heat by coming in contact with the walls of the cylinder. A E represents the actual work done or the line the indicator would make, and A D is the constant temperature or isothermal line, or the work that would be done if the air could be kept in a constant temperature. We may imagine the piston to start at A, moving to the right, the pressure as it increases is shown at different points by the line A E, which represents actual work done. We will assume the air to be compressed to 75 pounds gauge pressure, which will be accomplished when the piston arrives at C, which indicates the receiver pressure. It will be noticed that the line A E extends over the line C,

indicating a few more pounds, descending towards K to the 75 pound mark. This is due to the opening or lifting of the discharge valve which, on account of its weight and spring, requires a little higher pressure to be lifted from its seat, and the irregularity of the line is due to the fluttering of the valve. When the piston arrives at the end it comes to a stand-still, the flow of air ceases and the valve by action of its spring closes. On the return stroke of the piston the compressed air which, owing to the clearance was not discharged, will expand back until it equals atmospheric pressure, when the receiving valve will open and admit a fresh charge of free air. This accounts for the line K F being curved, which shows that when considering the capacity of the cylinder, the volume F G is lost and the same is true at O. This may amount to still more if the tension of the spring which acts on the valve is too strong, which prevents the valve from opening promptly, or the area of the valve is too small and the air

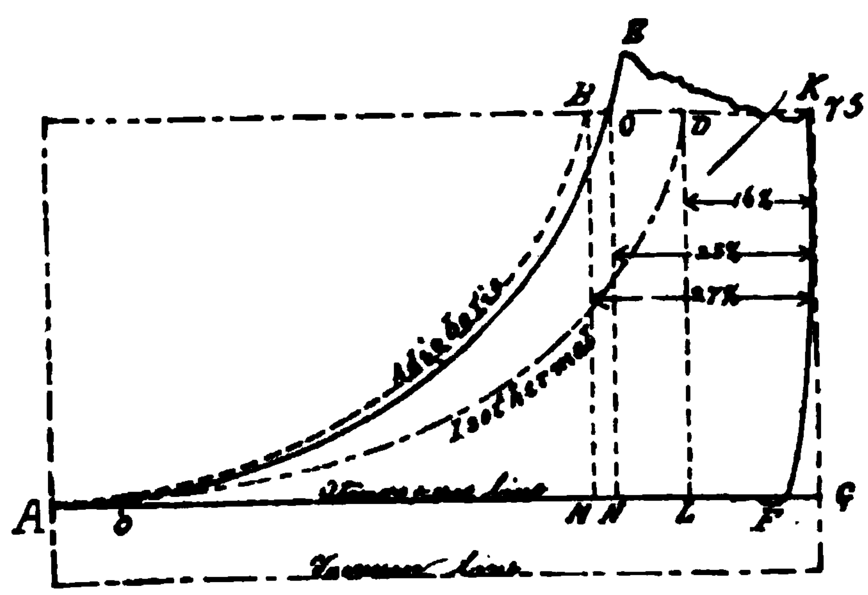


FIG. 3.

is restricted in its passage. If the indicator diagram follows the atmospheric line we know that such is not the case. The loss through clearance is really not a loss of power, the compressed air which remains in the cylinder helps to start off the piston on its return stroke, but it is a loss of capacity and the clearance may amount to from three to six per cent. Two to three per cent should be sufficient in a well designed compressor.

The temperature of the air at 75 pounds gauge pressure, without cooling is 419° F., but this is somewhat lower in the cylinder, due to the jacket cooling, and it is ascertained from actual reading of thermometers placed in the discharge pipe close to the cylinder, that the temperature is from 300° to 360°, depending on the speed and size of compressor. Referring to Figure 3, we have the volume C K N G, representing nearly 25 per cent of the free air volume at about 320°, which will be discharged into the receiver at each stroke of the piston. The air on its way from the compressor to the receiver will lose a great deal of heat by radiation and consequently be reduced in volume; and as the air

is used a considerable distance away from the compressor, it will have reached atmospheric temperature by the time it is used and the original volume C K N G will have shrunk to D K L G only about $^{16}/_{25}$ which it would have been if the air had been used hot as it left the compressor. Considering the foregoing we come to the conclusion that in our best constructed compressor after allowing for cooling, clearance and other causes we obtain nearly 16 per cent of the volume of free air, which was compressed to 75 pounds gauge pressure, to do useful work in the motor.

Capacity of Air Compressors.

To ascertain the capacity of an air compressor in cubic feet of free air per minute, we multiply the area of the cylinder by the feet of piston travel per minute, this gives the free air capacity; divide this by the number of atmospheres and the result will be the volume of compressed air which the compressor discharges per minute. To ascertain the number of atmospheres at any given pressure, add 15 pounds to the gauge pressure and divide by 15 pounds, the result will be the number of atmospheres. This method of calculation is, however, only theoretical and such results can not be obtained even in the best designed compressors. Allowance must be made for various losses, such as clearance, insufficient area of the inlet valves, leakage past the piston, leaks in valves, etc., which may cause a loss of from 15 to 25 per cent, while 8 to 10 per cent should be the maximum in well designed compressors and in calculating the capacity these conditions should be taken into consideration. The following table will be found useful to ascertain quickly the capacity of an air compressor, also to find the cubic contents of any cylinder or receiver. The first column is the diameter in inches, the second shows the cubic contents in feet for each foot in length. To find the capacity of an air cylinder, multiply the figure in the second column by the piston travel in feet per minute. Example: If the cylinder would be 12 inches in diameter, the cubic contents for one foot in length is .7854 cubic feet; if the stroke is 2 feet, this is multiplied by 2, $.7854 \times 2$ and there are two strokes to every revolution; this must be multiplied by 2 again $.7854 \times 2 \times 2$ and if the compressor makes 50 revolutions per minute the above figures must be multiplied by 50, thus: $.7854 \times 2 \times 2 \times 50 = 157.08$ cubic feet of free air capacity. This, divided by the number of atmospheres, which we will assume to be 4 would be $\frac{157}{4} = 39.25$ cubic feet of compressed air of 4 atmospheres. Now, we will consider the loss to be about 12 per cent, which is 4.5, the net capacity will be about 34.75 cubic feet of compressed air of 4 atmospheres per minute.

This applies to double-acting cylinders; if single-acting the result must be divided by two.

TABLE I.

CONTENTS OF CYLINDERS IN CUBIC FEET FOR EACH FOOT IN LENGTH.

Diameter Inches.	Cubic Contents.	Diameter Inches.	Cubic Contents	Diameter Inches.	Cubic Contents	Diameter Inches.	Cubic Contents	Diameter Inches.	Cubic Contents
1	.0055	5¾	.1803	10½	.6013	18½	1.867	31	5.241
1¼	.0085	6	.1963	10¾	.6303	19	1.969	32	5.585
1½	.0123	6¼	.2130	11	.6600	19½	2.074	33	5.940
1¾	.0168	6½	.2305	11¼	.6903	20	2.182	34	6.305
2	.0218	6¾	.2485	11½	.7213	20½	2.292	35	6.681
2¼	.0276	7	.2673	11¾	.7530	21	2.405	36	7.096
2½	.0341	7¼	.2868	12	.7854	21½	2.521	37	7.468
2¾	.0413	7½	.3068	12½	.8523	22	2.640	38	7.886
3	.0491	7¾	.3275	13	.9218	22½	2.761	39	8.296
3¼	.0576	8	.3490	13½	.9940	23	2.885	40	8.728
3½	.0668	8¼	.3713	14	1.069	23½	3.012	41	9.168
3¾	.0767	8½	.3940	14½	1.147	24	3.142	42	9.620
4	.0873	8¾	.4175	15	1.227	25	3.409	43	10.084
4¼	.0985	9	.4418	15½	1.310	26	3.687	44	10.560
4½	.1105	9¼	.4668	16	1.396	27	3.976	45	11.044
4¾	.1231	9½	.4923	16½	1.485	28	4.276	46	11.540
5	.1364	9¾	.5185	17	1.576	29	4.587	47	12.048
5¼	.1503	10	.5455	17½	1.670	30	4.909	48	12.566
5½	.1650	10¼	.5730	18	1.767				

Multi-Stage Air Compression.

The loss of heat, after the air being compressed and discharged, is a loss of power, or in other words the power that was used to compress the volume of air, which is afterwards lost through shrinkage, is lost also. Water-jacketing if not very effective, especially in cylinders of large diameter, the piston drives the air toward the end of the cylinder away from the walls too rapidly to have much effect. The heat loss is considerable, even in a moderate pressure up to 75 pounds, which is diagramatically explained in Figure 3. This loss can be avoided by employing a two-stage compressor or by compounding. Two-stage compression for a moderate pressure, say up to 100 pounds, has been long in use, with a fair claim of economy. In a two-stage compressor the air is only partly compressed in the low pressure cylinder and is then discharged into the inter cooler. See Figure 4 (the Sullivan Air Compressor). The inter cooler is a cast iron casing mounted upon the two air cylinders, and is provided with a suitable number of copper tubes, through which the cooling water circulates. The air is forced to travel

the length of the inter cooler three times by means of suitable deflecting plates. In this manner of cooling the air is split up into thin sheets and passing over a large cooling surface, the temperature is reduced to nearly its intake temperature before it arrives at the second or high pressure cylinder. In the high pressure cylinder it is compressed to its final pressure and then discharged into the receiver.

The cooling water first passes through the jacket of the high pressure cylinder and from there by means of pipe connection, through the jacket of the low pressure cylinder, and thence it traverses three times through the inter-cooler tubes, and leaves

FIG. 4.

the machine at the top of the inter-cooler shell. As nearly all the heat is absorbed in the inter-cooler, the rise in temperature of the circulating water in passing through the cylinder jackets before its arrival at the inter-cooler is insignificant. The following table, II, will serve to illustrate the large saving that is possible to be expected by compounding.

TABLE II.

POWER LOST BY ONE, TWO AND FOUR STAGE COMPRESSIONS.

Gauge Pressure.	One Stage.	Two Stage.	Four Stage.	Gauge Pressure.	One Stage.	Two Stage.	Four Stage.
60	30.00	13.38	4.65	1,000	96.80	39.00	16.90
80	34.00	15.12	5.04	1,200	106.15	40.00	17.45
100	38.00	17.10	8.00	1,400	108.00	41.60	17.70
200	52.35	23.20	0.01	1,600	110.00	42.90	18.40
400	68.60	29.70	12.40	1,800	116.80	44.40	19.12
600	83 75	32.65	15.06	2,000	121.70	44.60	20.00
800	90.00	35.80	16.74				

No account of jacket cooling is taken in columns 2, 3 and 4, it being well known among pneumatic engineers that water jackets, especially cylinder jackets, though useful and perhaps indispensable, are not efficient in cooling, especially in large compressors. The volume of air is too great in proportion to the cooling surface, and the time of compression too short, so that little or no cooling takes place.

Consulting Table II we learn that when air is compressed to 100 pounds in single-stage compressors, the heat loss may be 38 per cent; however, this condition does not exist in practice, as some heat is absorbed by the exposed parts of the machine; but it is safe to say that in large air compressors in which air is compressed to 100 pounds in single stage, the heat loss will be 30 per cent. This may be cut down to more than one-half by two stage compression theoretically, and in practice to nearly 10 per cent.

As higher pressures are used the gain in compounding is greater and multi-stage compression becomes a necessity. For instance air compressed to 200 pounds will reach a temperature of 673° F., which is above the melting point of lead and will fire wood work, and the effect of such great heat on the packing and on the lubricant that is used on compressors can be imagined. The economy in two-stage compression is largely gained up to 500 pounds, in three-stage up to 1,000 pounds, and in four-stage up to 3,000 pounds.

TABLE III.

LOSS OF PRESSURE THROUGH FRICTION OF AIR IN PIPES, IN POUNDS PER SQUARE INCH FOR EVERY 100 FEET LENGTH OF PIPE.

(Initial pressure 80 pounds at Receiver.)

Equivalent Volume of free air discharged per minute.	SIZE OF PIPES.												
	1"	1¼"	2'	2"	2½"	3"	4"	5"	6"	7"	8"	10"	12"	14"
25	.24	.12												
50	1.00	.45	.18											
75	2.4	1.00	.4											
100		1.7	.70	.13										
200			3.00	.50	1.75									
300				1.20	.38	.15								
400				2.15	.67	.27	.06							
500				3.30	1.10	.40	.10	.03	.012					
750					2.50	.91	.22	.07	.03	.013				
1,000						1 8	.40	.12	.05	.023	.012			
1,500						4.00	1.00	.30	.12	.052	.027			
2,000							1.60	.50	.20	.095	.048	.017		
3,000							3.70	1.20	.45	.22	.115	.036	.015	
4,000								2.00	.80	.39	.20	.07	.026	.012
5,000									1.30	.60	.30	.10	.041	.018
6,000									1.9	.85	.43	.15	.06	.028
7,500									3.00	1.40	.68	.22	.09	.04
10,000										2.5	1.25	.40	.17	.075

Transmission of Power.

In planning a transmission system of the compressed air power, it is very important to consider the future wants before deciding on the size of the main pipes. These main pipes should be of much larger size than is required for the present wants. Such mistakes are frequently made and as the demand for additional power increases, the pipes become too small, this causes friction and consequently loss of power.

In the table on opposite page the air losses in transmission in pounds per square inch for definite volumes through assigned pipe sizes, by the most used pressures in mining and mechanical operations, viz., 80 pounds pressure, are given.

Example:—An air compressor furnishes 1,000 cubic feet of free air per minute at a pressure of 80 pounds per square inch in the receiver; if this air is used at the end of a 4 inch pipe 2,000 feet long, the loss due to friction will be $20 \times .40 = 8$ pounds; and if the same amount of air and under the same pressure would be used at the end of a 6 inch pipe, the loss would be only $20 \times .05 = 1$ pound. Thus the importance of using larger pipes will be readily understood. The loss of pressure is not exactly proportional to the length of the pipe, but in practice it may be taken as such. There is also a slight loss due to the friction of the air itself at the mouth of the pipe when it leaves the receiver.

Leaks in compressors and pipes and receivers should be strictly guarded against. Air leaks are fully as expensive as steam leaks, and should never occur.

Hydraulic Air Compressors.

Many experiments have been made to compress air directly by falling water, without the aid of any moving machinery, and without expense of maintenance or attendance after installation.

One of the earliest devices is the trumpe which is illustrated in Figure 5. A smal stream of water can be used to compress air to such an extent that it can be applied to the air blast for a blacksmith forge. The water collected in the reservoir A descends in spout B, draws in the air through the air holes CC and forces it down into the air chamber D, striking an inclined plate E which facilitates the separation of the water from the air, which is confined to the top of the air chamber. The water settles at the bottom, from which it rises in return to escape at F. It will be readily understood that the air pressure depends upon the height of the return, the air in the air chamber being compressed to the extent due to the height of the return.

Various other experiments were made on this principle, and carried out by C. H. Taylor in the practical hydraulic air compressors at Magog, Quebec, and at Ainsworth, B. C.

FIG. 5.

The hydraulic compressor system of Mr. Taylor is illustrated in Figure 6, in which a large number of air tubes, c c, terminate at the conical entrance B, at a a. A supply of water to the chamber A A, and its flow down the pipe draws air through the

FIG. 6.

small pipes, carrying it down to the separating tank e e, where it is liberated by the pressure due to the hydrostatic head. The air is delivered through the pipe P, as shown in cut and the water rises through the open tail race R.

The compressor as erected at Magog, Quebec, gives in air power 62 per cent of the water power used and delivers 155 horse-power in compressed air at 52 pounds gauge pressure. A most remarkable feature of this system is that, notwithstanding

the air is compressed by the weight of the water and in actual contact with it, so compressed is delivered drier than when drawn in from the atmosphere.

This seems to be impossible, but it is well known that in high temperatures the air holds moisture longer than in lower temperatures. The contact with the water keeps down the temperature of air globules usually caused by the compression of air in compressors of the piston type, the moisture in air globules condenses and at the point of separation the air and water are absolutely separated. The compressor can be regulated to furnish any proportion from one-third of its capacity by the hand wheel S, by which the flow of water is regulated, but the pressure of the air remains the same. Should the volume of air taken down be greater than that being used it accumulates in the receiver until it forces the water below the lower end of the receiver and the surplus passes up with the return water, thereby forming an automatic safety valve. This is no doubt the cheapest method of compressing air, furnishing power at a uniform pressure and after once installed, without any expense.

Reheating Compressed Air.

One of the most important economies in the use of compressed air is obtained by the increased volume due to reheating. Reheaters of various types are in existence.

In Figure 7 a sectional view of one is given called the Rand Heater. The air enters at the side and passes up and around in the narrow space and leaves at the top of the heater. In a test made with a heater of this type having 8½ square feet of heating surface, 530 cubic feet or free air under 60 pounds of pressure were heated from 84° to 376° F. in one minute, with exhaust air from the motor, used as a forced draft, the temperature was raised to 450° F. from the same quantity of air. 300° is the most practicable temperature to operate motors and drills on account of the oil used for lubrication if used immediately, but if the air must travel some distance before being used in the motor or drill, it may be heated to a higher temperature to make up for loss in cooling on its way from the heater to the motor. As much as 35 per cent has been gained in reheating, which is undoubtedly a great advantage considering the slight cost for fuel.

Compressed Air Motors, Tools, Etc.

Any steam engine, steam-pump, that can be set in motion by the application of steam, and all appliances, which are used to economize the use of steam in direction of creating power, can be worked in connection with compressed air, and as engines

have been amply explained we will not follow this subject any further.

FIG. 7. FIG. 8.

Lifting Water by Compressed Air.

As before stated, any steam pump may be used in connection with compressed air, but in some instances the compressed air is directly applied to lift a body of water and does so continuously by employing an apparatus called the Pohle system, of which an illustration is given in Figure 8. The air lift pump proper consists of only two open end pipes, the larger one with an enlarged end-piece constituting the discharge pipe, and the

smaller one let into the enlarged end-piece of the discharge pipe is the air inlet pipe, through which the compressed air is conveyed from the receiver to the enlarged end-piece to the under side of the water to be raised. No valves, pistons, etc., are used or other moving parts within the pipes of the well. In starting the apparatus, compressed air is forced through the air pipe into the enlarged end at the bottom of the water pipe, thence by the inherent expansive force of the compressed air, layers of bubbles of air are formed in the water pipe, which lift and discharge the water layers through the upper end of the discharge pipes. The Pohle "air-lift" pump has been found to give above 80 per cent of efficiency from the air receiver in water pipes of large diameter, and, as a rule, above 70 per cent in smaller pipes. There is no repair to make on the pump and it retains its efficiency until the pipes rust through, while pumps of the piston type lose some of their efficiency from the first stroke they make, especially in water which contains sand or other substances injurious to metal. Figure 9 represents the same principle but water is lifted by compounding the air-lift, and is generally used to drain shallow water.

Pneumatic Hammer.

Figure 10 shows a sectional view of the Ross Hammer. A represents the outer casing, made from solid drawn steel tube, bored and fitted with a phosphor bronze liner, B, which forms the cylinder in which the piston works; E the striking piston made from steel forging, ground to fit the cylinder; D the exhaust port, open to the atmosphere through valve G, C and C1 the admission ports, admitting compressed air to alternate ends of the piston; K another port always open to the air supply; G the exhaust valve; H the trigger operating the same; F the handle, to which compressed air is admitted at the point F1; L a piston cushion, has always full and constant pressure behind it from the air supply through the port L1; and M shows the working tool.

It will be noticed that this hammer is started by opening the exhaust and not by an admission valve. The direction taken by the air when connected to the handle E1 will be readily seen by noticing the arrows. The piston is slightly reduced in diameter in the middle, and the two inside edges of the two collars thus produced form the cut off edges for pressure, while their outsides govern the exhaust ports. It will be seen that when the piston is in the middle of its stroke there is a dead point, the compressed air finding admission only to the chamber formed by the reduced portion of the piston, since the ports C and C1 are all cut off from admission of compressed air, but this does not interfere with its proper working as the port cover is very small. Moreover, when starting, the piston will fall either to one or the other

end of the cylinder by gravity, and when at work the momentum carries it over the dead point. The cut shows the front exhaust port open, and the piston just commencing its forward stroke. Air flows through K, thence through the port C, passing between the annular space formed between the liner and the outer casing,

FIG. 10.

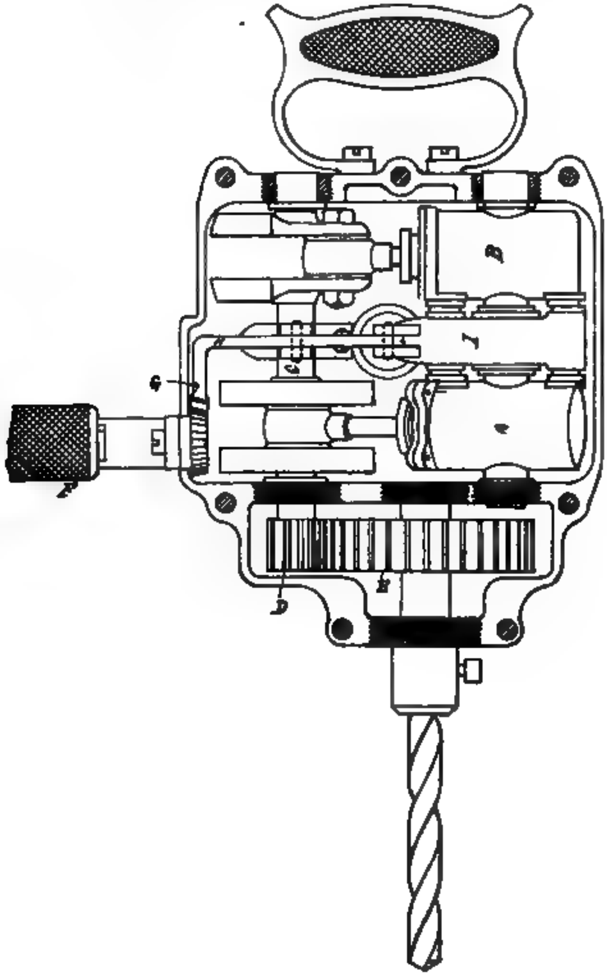
FIG. 9.

and back through C1 to back of piston, thus driving it forward. At the same time, exhaust takes place through D. The same action takes place on the backward stroke, when the forward ports, C and C1 are then in communication with K. In order, as far as possible, to eliminate vibration, a condition which is

present in all hammers, the cushion piston, L, has been introduced at the rear of the piston.

Pneumatic Drill.

Figure 11 shows the interior of the Whitlaw Drill with half the casing removed, showing the piston valve I and the passage of the air leading to the cylinder and the method of reversal. This type of drill is actuated by two double acting cylinders (oscillating) A and B driving a crank shaft C, to which is



attached a pinion D, driving the gear-wheel E, attached to the drill spindle. Its action is, therefore, at once apparent; by the rotating middle handle E which gears into the short rack G at the end of the lever H, the hollow portion of the piston valve I changes its position, with the result that a reversal takes place. The engine exhausts into casing, from which it escapes through suitable apertures. This machine can be used for all kinds of drilling, tapping, tube expanding, wood boring, etc. The machine is supplied with ample lubrication and is fitted with ball bearings throughout.

Oil governed pneumatic air hoist in Figure 12 represents a section of a pneumatic hoist governed by the use of oil. It will be noticed that an oil reservoir is formed in upper cylinder head, a pipe connected thereto extends down into the hollow piston rod and is kept tight at piston by means of a stuffing box. The oil reservoir is provided with a swing check valve and also with a regulating valve with screw stem which extends to the outside of the casting and is provided with a sprocket wheel and chain for regulation. When the piston moves downward, the oil in reservoir fills up the piston rod, through the swinging check valve. When the air is turned on, the piston only can move as fast as the oil is able to escape through the regulating valve. It makes no difference how the air is turned on, slow or fast, whether the hoist is loaded or not the speed is entirely governed by the oil.

GAS AND GASOLINE ENGINES

Gas engines are built on two and four-cycle styles. In the two-cycle styles the gas or vapor and air mixture is drawn into the cylinder during part of the forward stroke, fired, expanded with the motion of the piston and exhausted by the return stroke. This class of engines belongs to the earlier type of gas engines, using as much as 96 cubic feet of illuminating gas per horse-power per hour. This was considerably reduced, however, due to improvements that were made from time to time, until the gas consumption was reduced to about 36 cubic feet per indicated horse-power per hour.

The efficiency of this type of gas engine was never very great, seldom reaching 20 per cent of the heat value of the gas used. In the four-cycle type the mixture of gas and air is drawn into the cylinder by one stroke, compressed by the return stroke, fired and expanded in the third stroke, and exhausted by the fourth stroke. The efficiency of four-cycle engines is greatly advanced by compression. The pressure is much greater than in two-cycle engines owing to a more complete infusion of the mixture of gas or vapor and air and quicker firing.

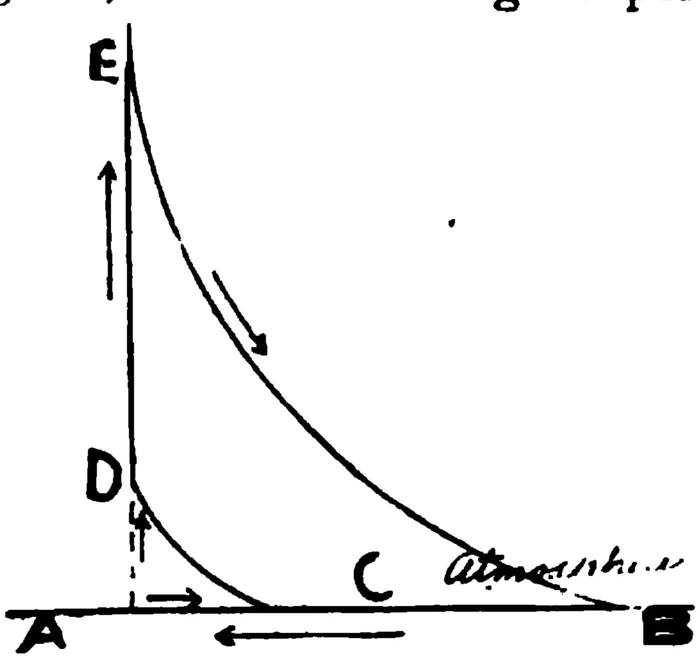


Fig. 1.

In Figure 1 an ideal card of work of a perfect compression cycle in which the gases are compressed is represented. A B is the atmospheric line, the piston stroke starting at C and compression being completed at D. It will be seen that additional pressure is instantly developed from D to E by combustion or heat at constant volume, doing work from E to B and exhausting along the atmospheric line B A. The gases in this case expand till their pressure falls to the atmospheric line, and their whole energy is supposed to be utilized. No heat is supposed to be lost by absorption of the cylinder walls or by radiation and no back pressure during exhaust or friction, is taken into consideration. Some serious difficulties may arise, due to excessive jacket cooling. In Figure 2 the cooling effects of walls are shown by

the lagging of the explosion curve, caused by the missing of several explosions. There is also some delay experienced in starting a gas engine. The indicator card I A D represents the normal condition of constant work in the cylinder; the curve I B D an interruption for several revolutions; and I C D a still longer interruption in the explosions with the engine in continuous motion.

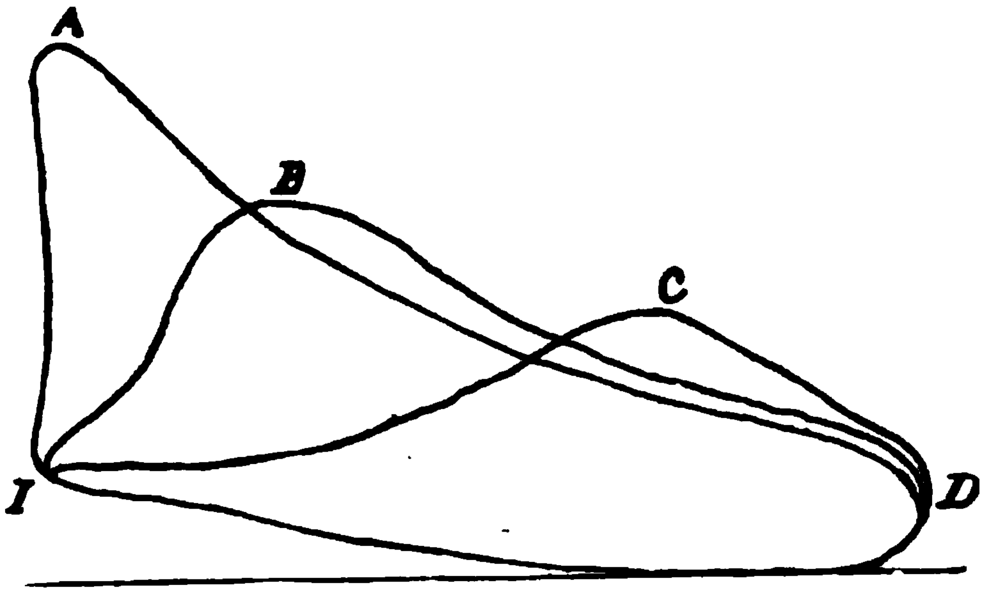


FIG. 2.

Experiments have been made in France to ascertain the efficiency of gas engines under various piston speeds, and it has been shown that the useful effect increases with the velocity of the piston—that is, with the rate of expansion of the burning gases with mixtures of uniform volumes. The diluted mixture, being slow burning, will have its time and pressure quickened by increasing the speed.

TABLE I.

EFFICIENCY DUE TO INCREASED PISTON SPEED.

MIXTURES.	Time of Explosion. Second.	Piston Speed Per Second.	Computed Work Diagram. Foot Pounds	Theoretical Work of the Gas. Foot Pounds	Efficiency.
1 Volume of Coal Gas to 9.4 vol. air (.1093 cubic feet mixture)	.53	1.181	70.8	4917	1.44
1 Volume of Coal Gas to 9.4 vol. air (.1093 cubic feet mixture)	.40	1.64	85.3	4917	1.70
1 Volume of Coal Gas to 9.4 vol. air (.1093 cubic feet mixture)	.25	3.01	105.5	4917	2.10
1 Volume of Coal Gas to 9.4 vol. air (.1093 cubic feet mixture)	.16	4.55	125.8	4917	2.60
1 Volume of Coal Gas to 6.33 vol. air (.073 cubic feet mixture)	.15	5.57	127.2	4793	2.60
1 Volume of Coal Gas to 6.33 vol. air (.073 cubic feet mixture)	.09	9.51	289.9	4792	6.00
1 Volume of Coal Gas to 6.33 vol. air (.073 cubic feet mixture)	.06	14.1	364.4	4792	7.50

This trial gives unmistakable evidence that the useful effect increases with the velocity of the piston—that is, with the rate of expansion of burning gases.

Temperature of Jacket Water.

Dugald Clerk, in England, a high authority on practical work with gas engines, ascertained that 10 per cent of gas for a certain amount of power can be saved by using water for jacket cooling of such temperature that the ejected water is near the boiling point, and according to his opinion a still higher temperature may be used. This could be accomplished by elevating the water tank and adjusting the air-cooling surface so as to maintain the inlet water at a temperature just below the boiling point, and by rapid circulation through the jacket return the water a few degrees above the boiling point. A cold water supply, say of 60° Fahr., circulated so slow as to allow the ejected water to flow off at a temperature near the boiling point, keeps the temperature of the bottom of the cylinder a great deal lower than that of the top, with a loss of economy of gas, as well as water, if it is obtained by measurement.

The Material of Power in Explosive Engines.

The composition of gases, gasoline, petroleum oil, and air as elements of combustion and force in explosive engines is of great importance in comparison to heat and motor efficiency. The material of power in explosive engines for gases, gasoline and petroleum oils is found in the following table:

TABLE II.

MATERIALS OF POWER IN EXPLOSIVE ENGINES—GASES, GASOLINE, PETROLEUM OILS.

VARIOUS GASES, VAPORS AND OTHER COMBUSTIBLES.	Heat Units Per Pound.	Heat Units Per Cubic Foot.	Foot Pounds Per Cubic Foot.
Hydrogen	61,560	239.5	226,580
Carbon	14,540	....	....
Crude Petroleum, West Va., spec. grav. .873	18,324	....	....
Light Petroleum, Pennsylvania, spec. grav. .841	18,401	....	....
Benzine, C_6H_6	18,448	....	....
Gasoline	11,000	....	....
28 Candle-power Illuminating Gas	....	950.	773,400
19 Candle-power Illuminating Gas	....	800.	617,400
15 Candle-power Illuminating Gas	....	620.	478,640
Water Gas, American	....	185.	142,820
Gasoline Vapor	11,000	690.	492,680
Natural Gas, Leechburg, Pa	....	584.	450,848
Natural Gas, Pittsburg, Pa	....	495.	382,140

Oil gas as used in many towns in the United States for lighting, which by experiments made with mixtures of gas and air, gave the following explosive effects:

Oil-gas Volumes.	Air Volume.	Explosive Effect.
1	4.9	None.
1	5.6 to 5.8	Slight.
1	6. to 6.5	Heavy.
1	7. to 9.0	Very heavy.
1	10. to 13.0	Heavy.
1	14. to 16.0	Slight.
1	17. to 17.7	Very. slight.
1	18. to 22.0	None.

It will be noticed that mixtures varying from 1 volume of gas to 6 of air, and all the way from 1 to 13 of air, are available for use in gas engines for different speeds and power regulation; and that one volume of gas to from 7 to 9 of air gives the best results.

Carburetters.

Gasoline, naphtha and petroleum oil for operating internal combustion engines find a good deal of favor, especially at places where coal gas can not be obtained. When so used the air is passed over the liquid, the rising vapors mingling with the air. or the fluid is heated by means of the exhaust, or directly injected in small portions into the air inlet or under the valve and thence into the clearance space of the cylinder. This latter style of using gasoline is always a risk, making it a source of danger.

Much of the risk and inconvenience of handling gasoline for motive power may be avoided by using the mixture of air and gasoline vapor as a gas. The presence of gasoline in quantity in buildings will increase the insurance risk, and is always liable to cause accidents if not carefully handled. An arrangement which vaporizes the gasoline and also secures a perfect mixture with the air is shown in section in Figure 3, called the Daimler Carburetter. The gasoline, which is supposed to be stored outside of the building, enters the Carburetter at the top and passes down into the tank in the small central pipe as indicated by the arrows. The float B by its weight keeps a constant level in conical cup D; here the evaporation takes place. The hot air, which is heated by passing through a jacket on the exhaust pipe, passes down through the guide tube and out through the perforation beneath the fluid into the conical cup D, then over two diaphragms, and through the perforated screen into the vapor tube. The perforated screens in both the inlet and outlet chambers prevent the jerky motion of the piston.

FIG. 3.

Another arrangement, which is largely in use in connection with marine engines, is represented in Figure 4, called an atomizer and vaporizer. In this arrangement the gasoline is stored in the bow of the boat and the atomizer at the base of the engine. The gasoline, which flows by gravity to the chamber F, is stopped by the conical deep seated valve E. The cage of the air inlet valve D is screwed into the metal box at B and is adjustable so as to bring the push centers of the valve D to the proper distance for operating the gasoline inlet valve E. The lift of the air valve D is also adjustable in its lift by the lock-nuts I on the spindle C, which is guided by the cross bar in upper part of the cage. The

main air inlet is at H, with a diffusion inlet at G regulated by a plug-cock. The gasoline is thoroughly atomized by action of the two valves E and D, and meeting the fresh air G is vaporized in its passage through the pipe and inlet valve-chamber.

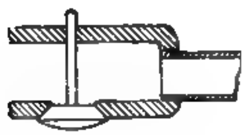


Fig. 4.

Igniters and Exploders.

The devices in use for igniting the explosive charge are classed in three styles; the direct flame-contact, the hot tube and the electric igniter. The direct flame contact is probably the simplest; an ordinary Bunsen burner may be set just below the ignition port, a slide valve opening the port at the proper time brings the explosive mixture in contact with the flame and explodes the charge. The hot tube, as illustrated in Figure 5, is inclosed at one end and its open end communicates with the ignition port. This tube is heated to a red heat by a Bunsen burner. The adjustment of the length of the tube and position of the heating flame, so that ignition will take place at the proper time, is a somewhat delicate matter and has to be worked out experimentally for each style of engine. Figure 6 shows the slide igniter in connection with the hot tube, the ignition port is opened at the proper time and the compressed gases enter this hot tube, the valve is kept open during the whole forward stroke of the piston. This form of igniter is called a time igniter. The

ignition tube is made short and may be of platinum or porcelain. Owing to the perishable nature of iron ignition tubes the porcelain tube was adopted, also the platinum tube, but owing to the cost of platinum the porcelain tube is generally used. When properly set the wear on porcelain tubes is slight, and if not accidentally broken will last a year or more. The method of setting porcelain tubes is shown in Figure 5; they are clamped in a socket between asbestos packing, either dry or moistened with wet clay.

What is considered to be the best metallic tube in the market is the nickel alloy, imported in the form of rods in six feet lengths from Schwerte, Germany. The sizes are 3/8, 1/2, 9/16, 5/8

FIG. 5.

FIG. 6.

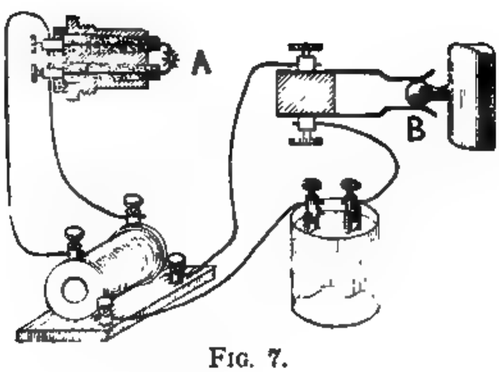


FIG. 7.

and 11/16" diameter and can be had of Hermán Baker & Co., 101 Duane Street, New York, at a cost of ninety cents a pound. They also furnish finished tubes of all sizes to order.

Metal tubes should never be heated to a white heat, a uniform ring of red heat is all that is required. By following this course the tube will last a long time.

Electric igniters are favored a great deal, especially in marine engines. In Figure 7 a sparking device is shown as used in the Priestman engine. A spark is transmitted between two platinum electrodes A by a contact-breaker B. Another style is shown in Figure 8. A contact-piece, which is operated by an insulated rod, suddenly slipping off a fixed stud, as indicated by dotted lines, produces the sparking. The current may be obtained by a primary or storage battery or by a small generator driven by the

FIG. 8.

engine. In this case the engine is started with a battery and when it has run for a short time the current from the generator is switched on and the battery is disconnected.

Governors.

The methods for regulating the speed of gas engines are based on four principles: (1) By decreasing the supply of the hydrocarbon element; (2) by completely cutting off the supply; (3) by holding the exhaust valve open or closed during one or more revolutions; (4) in electrical ignition, by arresting the operation of the sparking device. The second method is claimed to give the best results. Such an arrangement is shown in Figures 9 and 10. A roller attached to the end of a push rod is operating on a cam. The bell crank, which stands under the control of a

centrifugal governor, is placed with its forge astride of the roller which rides on the cam of the secondary shaft. The disk has a lateral movement so that the action of the governor leads the roller on and off the cam, causing the valve to remain on its seat for one or more revolutions.

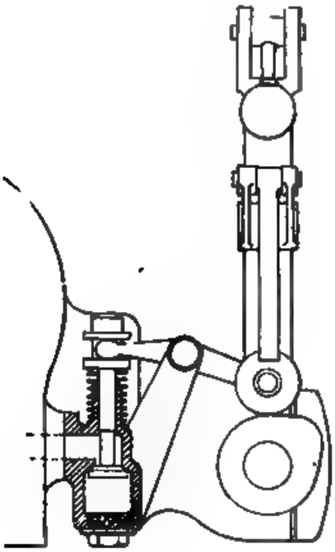


FIG. 9. FIG. 10.

Lubrication of the Cylinder.

Owing to the intense hot gases in immediate contact with the lubricating oil, which tends to evaporate the oil very rapidly, it is of great importance that the oil is fed regular. To avoid gumming, the oil that is used should be of a kind that is best adapted for this severe heat trial and should be fed in constant flow, not too much, but as to flow into the combustion chambers sufficiently. Oil when fed too heavily will blow through the exhaust and clog the passages with oil soot; oil cups of various styles are employed, but are very unreliable.

In Figure 11 an automatic oiler is shown, one of the many kinds in use throughout the country, giving excellent results. The pin which revolves with the crank inside the casing dips into the oil below and carries a portion of it on its upward motion up and wipes it off on the stationary pin from which the oil drops in passage to the cylinder. The shaft may be set in motion by a small belt from the cam shaft.

Testing Gas Engines.

No standard rule for rating the horse-power of a gas engine, as in the case of steam engines, is in force up to this time. The effective horse-power may be ascertained by means of the indication card, taken when the engine is under full load, by applying the brake as it is done in shops, and the engine is then rated to so many brake horse-power. (B. H.-P.) (Mean Pressure of the Indicator Card on page 600.)

FIG. 11.

The most satisfactory way to test an explosive engine is probably to connect it to a dynamo, arrange a short system of wiring with a volt and ampere meter and a sufficient number of 16 candle power lamps in the circuit of a standard voltage and known amperage. The trial should be continued for a length of time, the consumption of fuel and speed observed and, if properly arranged, such a test is perfectly reliable. This will ascertain the power in kilowatts, from which the actual horse-power of the engine may be computed and the cost for fuel per horse-power per hour may be ascertained.

Care and Management of Gas Engines.

The management of gas and gasoline engines does not require an experienced engineer, yet it requires an attendant of some ability to properly run such engines, to detect leaks, loose journals, pins, etc., in time to avoid stoppage, which otherwise might cause unnecessary delay or very expensive repairs, also the regulation of the explosive mixture, which is generally explained in instruction pamphlets of the builder. Next is cleanliness; the cylinder, valves and exhaust pipes should be cleaned at short intervals, depending on the kind of fuel used. The outside sur-

faces should be wiped before starting, or at the close of work every day, especially when located in a room where dust and dirt are liable to stick to the oily surfaces. In such cases the engine should be partitioned off, as dust and gritty substances which stick to the wearing parts greatly damage the engine.

In starting a motor, it should always be turned over in the direction the engine runs. Should the compression make this difficult, the relief valve may be opened (most engines are provided with such a valve), or the exhaust or air valve may be opened to clear the cylinder, if an overcharge of gas or failure of ignition has been made at the first turn.

Some of the troubles that may arise are severe explosions, caused by several misfires, by which the cylinder may become overcharged with the combustible mixture. This may be caused by irregular work on the engine. Again, by a misfire from failure in the igniter an explosive charge is intensified at the next ignition or exploded in the exhaust pipe. All such explosions may be attributed to irregular work, or to irregularity in operation of the valves or igniter. Although gas engines are all built strong enough to withstand such explosions, they can be avoided by proper management. In examining the interior of a gas or gasoline engine the fuel inlet must be closed, the engine should be turned several revolutions to exhaust all gases which may be present in the ports and cylinder, take-off plugs or caps, using a light near them to test if any gases are left and all fuel supply closed.

The exhaust pipe should never be turned into a chimney. The power of a gas engine is sometimes not fully developed, owing to insufficient gas supply. A gas bag is a good indicator of this condition; the flabby appearance of the bag indicates that engine draws more gas than is supplied, showing that gas pipe or meter is too small.

There are many points in management of motors that can not be discussed in a general way owing to the many and various details and designs. By studying the directions given by the builder any person of ordinary intelligence and tact in handling moving machinery may be intrusted to run a gas engine.

Operation of Gas and Gasoline Engines.

Owing to the limited space in this work we give the principles of only a few of the various kinds of gas engines. The principles of gas and gasoline and oil engines are the same, only differing in form and efficiency. The two-cycle non-compression type, although there are some in use, is fast disappearing; we therefore take no notice of this type.

Operation of a Two-Cycle Compression Engine.

In Figure 12 a sectional view of the Grohman Engine is shown. It may be operated either with gas or gasoline and its ingenious construction is very interesting. This engine has two cylinders of different diameters, A and B, cast in one piece, in which two pistons, each fitting one of the cylinders, move. The

FIG. 12.

pistons are of hollow trunk type and connected to the crank shaft in the ordinary way by means of a connecting rod acting upon a crank. The cylinder A is the working cylinder and the larger one, B, is the compression cylinder. C is the exhaust valve operated by an eccentric D. The exhaust port E extends down to lowest point of the piston stroke, meeting another exhaust port F, which is opened when the piston arrives at its lowest point.

Another port communicates with a port in the piston at the same time at G. The crank-chamber is inclosed air tight with an air intake valve at H. The gasoline flows to the evaporator J and is mixed first with hot and then with cold air, which causes the evaporation; both are regulated by valves.

The operation of this engine is as follows: The gasoline vapor having arrived at the intake valve (not shown) is drawn into the compression cylinder on the down stroke of the piston through the port I. The free air that is present in crank-chamber is compressed at the same time. The piston when at its lowest point opens the exhaust port F and at the same time brings the

FIG. 13.

crank-chamber in communication with the working cylinder, the air in crank-chamber being compressed rushes up and helps clear the exhaust, which is partly relieved at port F; on the return stroke the exhaust is opened and the remaining burnt gases are exhausted. The fresh charge which on the up-stroke was compressed in the compression cylinder B at the same time is confined in the valve chamber at great pressure. The piston having arrived at the top the exhaust valve is closed and the poppet valve K in the chamber is opened by another eccentric, the compressed charge rushes up into the working chamber, is ignited, exploded and the piston forced downward to take a fresh charge.

Operation of Four-Cycle Compression Engines.

A sectional view of a four-cycle compression gas and gasoline engine is given in Figure 13. It is of English design and its construction is very simple. It is called the Petter Engine and is built for motor carriage and also for stationary use. The drawing represents the stationary type and operation is as follows: The gasoline gravitates to the inlet valve A through percolator C and is atomized by the air drawn in at B on the forward stroke of the piston, causing a suction and the charge is compressed on the return stroke, ignited, exploded, and the piston by this sudden expansion is forced forward and transfers this power to the crank and fly wheel. On the return stroke the exhaust valve, which is operated by a long rocker as shown in dotted lines, opens and relieves the exhaust and the engine is ready for another charge.

Naphtha Vapor Engines.

Unlike other gas and gasoline engines is the naphtha vapor engine, used mostly for marine purposes, in pleasure yachts and launches. This engine is propelled by the vapor of a light grade of gasoline, which evaporates at a comparatively low temperature under the required pressure for operating the engine. See Figure 14, which gives in a general outline the principles thereof. There being no pressure in the coils in chamber above the engine before starting, the liquid enters at the lower part of the coil. A hand-pump is used to inject some vapor in burner below the coil when starting the engine. When evaporation takes place the vapors, being confined, create a pressure which can be regulated by the burner. The vapor rises to the top of the coil and passes down in the central pipe into the valve chamber on top of the cylinders. The slide valves are moved by a three-way eccentric or crank shaft which revolves at the same speed as the main shaft. The valve shaft is operated by the latter by means of gearing. The exhaust enters the crank chamber, from this it enters a pipe which leads to a condenser, where the vapors are liquified and

returned into the supply tank to be again used. When the engine is once started the liquid is forced into the coil by a small pump operated by an eccentric on the main shaft and the burner receives its supply from the central vapor pipe in the coil chamber and is regulated by a valve. The safety valve, which is not shown, is shaped in such a way that all vapors are led to the con-

FIG. 14.

denser, instead of discharging into the atmosphere and are, therefore, saved to be used again. These motors have gained high reputation for safety, durability and economy in the last ten years.

Gas Engines for Electric Lighting.

The economy of the gas engine in connection with electric lighting can not be doubted, as various tests in the United States and Europe have been made with excellent results.

In a trial with a Crossley engine of 54 I. H.-P., running a 25½ kilowatt generator (34 electrical H.-P.), lighting 400 incandescent lamps of 16 candle power, consumed 1,130 cubic feet of gas per hour, or 2.8 cubic feet per lamp per hour. The gas used was 16 candle power at 5 cubic feet per hour. This gas if used for direct lighting would have produced $\frac{1130}{5}=226-16$ candle power gas light, a little more than half of the lights produced in generator.

In a trial of eleven days with a 10 H.-P. four-cycle engine of the Raymond vertical type, belted to 150 light direct-current generator making 1,600 revolutions per minute, with the current measured by a recording wattmeter giving a steady current to ninety 16-candle-power lamps on a factory circuit, the total cost of gas at $1.50 per 1,000 feet with lubricating oil included was 20.16. The kilowatts produced by measure were 239.1, or a cost of .0844 cent per kilowatt. The price of the current by the same measure from the electric company was 20 cents per kilowatt, therefore, a saving of 57 per cent. Gas at from 80 cents to $1 per 1,000 cubic feet would reduce this considerably.

Mean Pressure of the Indicator Card.

For obtaining the indicated horse-power of a gas engine, the mean effective pressure as shown by the card, Figure 15, may be obtained by dividing the length of the card into ten or any convenient number of parts vertically, for a four-cycle compression engine. For each section measure the average between the curve of compression and the curve of expansion with a scale corresponding with that of the indicator spring number. Add the measured distances together and divide by the number of spaces

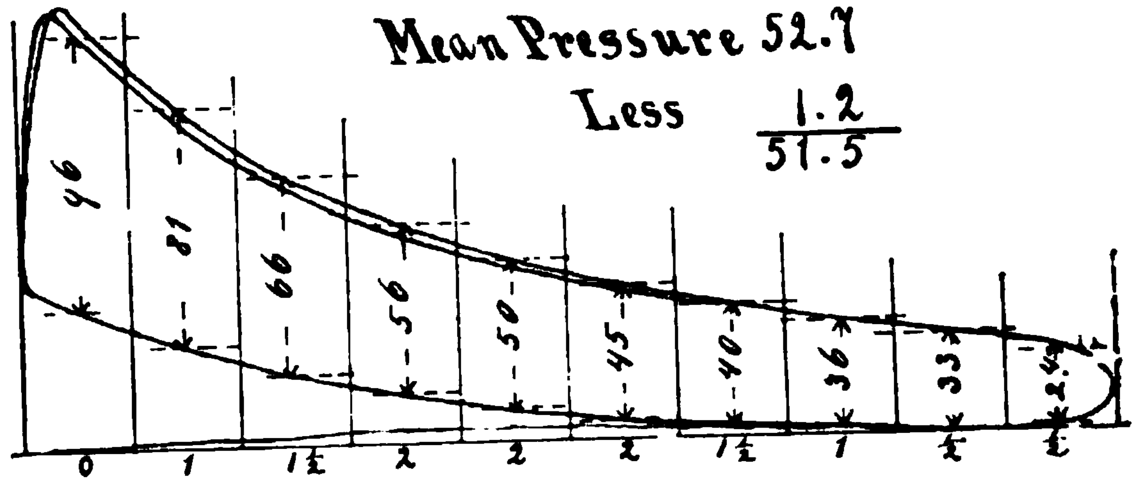


FIG. 15.

for the mean pressure. With the mean pressure multiply the area of the piston for the gross pressure. If there have been no misfires, then one-half the number of the revolutions multiplied by the stroke and by the gross pressure, and the product divided by 33,000 will give the indicated horse-power. If there is discrepancy along the atmospheric line by obstruction of the exhaust or suction stroke, the average must be deducted from the mean pressure. In order to obtain the desired result the indicator card must be taken when the engine is running steady and under full load. During the moment the pencil is on the card there should be no misfires recorded, in order that the card represents the true indicated horse-power of the engine. A record of the speed of the engine should be taken at the same time as the card, but the measurement of the quantity of gas used can not be accurately observed on the dial of an ordinary gas meter during the few moments. For the gas record, the engine should be run at least five minutes at the same speed and load, and an exact count of the number of explosions made. The number of cubic feet of gas indicated by the meter for a few minutes' run multiplied by its hour exponent and divided by the indicated horse-power by the card, or actual horse-power by brake, will give the required commercial rating of the engine as to its economy.

If gasoline or oil is used for fuel the detail of operation is the same as for gas, with the only difference of an exact measurement of the fluid actually consumed in an hour's run under full load. The misfires, or rather mischarges, are of no importance when an engine is running under constant load, being caused by overspeed and the overspeed and underspeed should make fair balance for the average of the run as indicated by the speed counter.

MECHANICAL REFRIGERATION

In reducing the temperature of a body and keeping the same below the temperature of the surrounding atmosphere, by artificial means, we call this Mechanical Refrigeration.

This can be brought about in many different ways:

First. By transfering the heat of a warmer body to a colder one (circulation of brine).

Second. By compressing and expanding air.

Third. By melting and dissolving solids (by melting of ice, dissolving salts in water).

Fourth. By evaporating liquids which have a low boiling point. The latent heat of evaporation represents the amount of cold that can be produced by evaporating liquid ammonia, liquid carbonic acid, liquid sulphuric acid, ether, etc.

Nearly all the machines used now-a-days to effect refrigeration on a large scale, are principally based on the evaporation of liquids to produce the desired cold. Preference is given to anhydrous ammonia, which on account of its great heat-absorbing power is generally in use, and therefore, we will proceed to explain how the production of cold is brought about by the aid of this liquid.

Anhydrous Ammonia.

Anhydrous Ammonia will boil at a temperature of 28½° below zero. For instance, take a vessel of liquid ammonia, and thrust it into a snow bank at 32° F. and it would bear about the same relation to the snow bank as a vessel of water thrust into a fire. In both cases there would be an evaporation of the liquids and absorption of heat by the resulting vapor. To make this clear and make it appear as plain as possible, we will say further, that the heat to evaporate the ammonia was taken out of the snow bank, which is even made colder than it was before. The idea exists that heat should be hot enough to burn and it is difficult for most people to form any other conception. When we take into consideration that the absolute zero of the negative scale is 461° below the zero of thermometers, you will comprehend that within this great range it is more a question of relative difference of temperatures between two bodies brought into contact, that determines the amount of heat that is lost by one and gained by the other, than the exact position in degrees they occupy upon the

thermometer scale. The hottest will invariably impart it to the coldest until temperatures are equalized, and in the case of ammonia whose boiling point is 28½° below zero, it will continue to boil at atmospheric pressure and carry off heat as long as it is in contact with any substance hotter than itself, or above 28½° below zero, making that substance continually cooler by absorbing its heat, or at least until it has been reduced to a temperature corresponding to the pressure upon which the ammonia gas is formed; this point reached, the ammonia will cease to boil or evaporate and remain in a liquid state.

Relation of Pressure and Temperature.

Pressure and temperature are inter-related, that is to say, at a certain pressure saturated gas has a corresponding temperature, and this is also the case with ammonia. Hence if the gas, while subjected to a certain uniform pressure, be discharged into an air tight vessel which is being constantly cooled by water of somewhat lower temperature than that due to the pressure of the gas, the vapor will necessarily under these conditions collapse and be condensed inside of the vessel and go back to the liquid form. The temperature of the water available for use on the vessel (condenser) determines the pressure to which the gas must be subjected in order to raise its boiling point or artificial atmosphere high enough so it can not exist as vapor when chilled by contact with condensing surfaces slightly colder than itself, but it will collapse. The pressure to which the gas is subjected ranges from 125 to 175 pounds to square inch according to temperature of water as below stated.

Operation of Apparatus.

One might think an apparatus as shown in Figure 1 would answer the purpose, as long as the evaporation of ammonia takes place in the evaporating coils to absorb the heat, making the compressor pump unnecessary. This would greatly simplify the plant, but if cost of the ammonia is considered such an apparatus is out of the question. In Figure 1, by means of which the ammonia is evaporated, compressed and condensed in order to be used again, the operation being continuous as long as the machinery is kept in motion. Referring to Figure 1a the apparatus being charged with sufficient pure ammonia, which we will, for simplicity, assume to be stored in the lower part of the condenser C. A small cock or expansion valve controlling a pipe leading to a congealer or brine tank A is slightly opened, thus allowing the liquid to pass into the evaporating coils. These coils by the way, really perform the same duty as a tube or flue in a flue boiler.

The steaming capacity of a boiler depends on the amount of heating surface and the same is true of the capacity of heating surface presented by the coils of the evaporator. The heat is transmitted through the coils from the surrounding substance to the ammonia liquid which is boiled into a vapor the same as water is boiled into steam in a steam boiler. The surrounding substances part with an equivalent amount of heat and thus become cooler,

FIG. 1.

FIG. 1a.

the amount taken up and made negative being in proportion to the pounds of liquid ammonia evaporated, this being under control of a cock or valve leading from the condenser (called the expansion valve). As the gas begins to form in the evaporator, the compressor pump B is set in motion at such a speed as to carry away the gas as fast as formed, which is discharged into the condenser under such a pressure as will bring about a condensation and restore the gas to a liquid state, the operation being continu-

ous as long as the machine is kept in motion. To utilize the cold thus produced for refrigeration, two methods are followed: one by pumping the cold brine so cooled through a system of pipes to the apartment to be cooled, called the brine system, or we may place the evaporating coil directly in the rooms to be cooled, called direct expansion system.

Brine System.

In this method the evaporating coils are placed in the tank which is filled with strong brine made of common salt, which is well known will not freeze at temperatures below zero. This is the brine tank also called the congealer. The evaporating or expansion of the ammonia in these coils robs the brine of heat as before explained, the process of storing cold going on continuously and being regulated at the gas-expansion valve. To make use of the cold thus manufactured, the chilled brine or non-freezing liquid is circulated by means of a pump through coils of pipes, which are placed on the ceiling or sides of walls of the apartments to be refrigerated, the process being similar to heating rooms by steam. The cold brine by circulating along the pipes becomes warmer, by taking up the heat of the rooms, and is finally returned to the brine tank, where it is again cooled by the ammonia coils and again circulated. The operation is continuous.

A brine plant consists of: (1) Compressor pump. (2) Condenser. (3) Brine tank. (4) Ammonia expansion coils. (5) Brine pump. (6) Circulating pipes.

Advantage of the Brine System.

Sometimes the circulation of brine for refrigeration is preferred to that of the direct expansion system for the following reasons: There is less ammonia required to charge the brine system than in direct expansion system, thereby lowering the cost of this item of expense. The machinery and brine cooling apparatus may be compactly arranged in the engine room, making it convenient for the care and management of the engineer. By installing the machine system and brine tanks of ample capacity, the body of brine which has been cooled during the day can be circulated during the night, thus keeping the rooms and apartments at the required temperatures, and save the expense of a night engineer to run the machine, as a fireman or a watchman can care for the circulating pump.

How to Prepare Brine.

Brine should not be made any stronger than is necessary to prevent it from freezing, as we notice from the table given at the end of this chapter. The specific heat growing less as the con-

centration of the brine increases, and consequently the stronger the brine is made the less heat a given amount of brine will convey between certain definite temperatures. There is another danger with the use of too strong brine in refrigeration; such being subject to the low temperature in the refrigerator has a tendency to deposit salt in the pipes causing clogging, etc. For this reason a brine should never contain more than 25 per cent of salt, this being as much as will be held in the solution at 0° F. The proper concentration of salt brine in individual cases can be readily found in Table I on page 608. For instance, if the brine leaves the tank at a temperature of 15° F., it would not be advisable to use a solution containing more than 15 per cent salt, as from the above mentioned table it will be noticed that such solution will not freeze at that temperature, and if the temperature is never below 20° F., a brine containing only 10 per cent of salt would be sufficient.

In both cases the brine will be sufficiently strong to prevent freezing, which is all that is required. The strength of the brine can be readily ascertained by means of a salometer, which is simple; a hydrometer stem allowed to float in the brine and the line to which it sinks reel off; referring to the above mentioned table the degree thus shown by the salometer can be readily converted into percentage of salt.

FIG. 3.

A Very Easy Method of Preparing Brine.

A simple apparatus can be made of a good sized water tight barrel or cask as follows: Fit a false bottom or wooden grating about six or eight inches from the bottom, this can be made of small strips of wood about an inch square and placed not over one-half inch apart. This should be supported by two strips of board six or seven inches wide, placed on edge and nailed to the bottom. (See Figure 3.) These boards should have several holes bored near the bottom to permit a free passage of the water. The water inlet must be below the false bottom, about 1¼ inch pipe, a single thickness of burlaps should be stretched over the false bottom and tacked on the sides of the barrel, the outlet pipe should be larger, about 1½ inch pipe, and should be located about five inches below the top of the barrel. Fill the barrel with salt and turn on the water, no stirring is required, skim off all waste matter and provide the outlet with a strainer of some kind to prevent chips, etc., from getting into the brine.

TABLE I.

TABLE OF BRINE SOLUTION.

(Chloride of Sodium—Common Salts.)

Percentage of Salt by Weight.	Degrees on Salometer at 60° F.	Specific Gravity of 60° F.	Specific Heat.	Weight of One Gallon.	Pounds of Salt in One Gallon.	Pounds of Water in One Gallon.	Weight of One Cubic Foot.	Pounds of Salt in One Cubic Foot.	Pounds of Water in One Cubic Foot.	Freezing Point, Degrees F.
0	0	1.	1.	8 35	0.	8.35	62.4	0.	62.4	32.
1	4	1.007	0.992	8.4	0.084	8.316	62.8	0.628	62.172	31.8
5	20	1.037	0.96	8.65	0.432	8.218	64 7	3.237	61.465	25.4
10	40	1.073	0.892	8.95	0.895	8.055	66.95	6.695	60.253	18.6
15	60	1.115	0.855	9.3	1.395	7.905	69 57	10.435	59.134	12 2
20	80	1.150	0.829	9 6	1.92	7.68	71.76	14.352	57.408	6 86
25	100	1.191	0.783	9.94	2.485	7.455	74.26	18.565	55.695	1.00

Calcium Brine.

Calcium brine is prepared in a similar manner, for strength and proportion, see Table II. Some engineers prefer to use chloride of calcium for the preparation of brine in preference to common salt. It is higher in price than the latter, but is said to keep the pipes cleaner, causing a better conduction of heat. The freezing point can, by its use, be depressed several degrees lower than by the use of common salt, and for this reason its use may be advisable in some extreme cases.

TABLE II.

TABLE OF CHLORIDE OF CALCIUM SOLUTION.

Specific Gravity at 64° F.	Degree Beaume at 64° F.	Degree Salometer at 64° F.	Per Cent of $CaCl_2$	Freezing Point, in Degrees F.	Ammonia of Gauge Pressure. Pounds per sq. inch.
1.007	1	4	0.943	+31.20	46
1.014	2	8	1.886	+30.40	45
1.021	3	12	2.829	+29.60	44
1.028	4	16	3.772	+28.80	43
1.035	5	20	4.715	+28.00	42
1.043	6	24	5.658	+26.89	41
1.050	7	28	6.601	+25.78	40
1.058	8	32	7.544	+24.67	38
1.065	9	36	8.487	+23.56	37
1.073	10	40	9.430	+22.09	35.5
1.081	11	44	10.373	+20.62	34
1.089	12	48	11.316	+19.14	32.5
1.097	13	52	12.259	+17.67	30.5
1.105	14	56	13.202	+15.75	29
1.114	15	60	14.145	+13.82	27
1.112	16	64	15.088	+11 89	25
1.131	17	68	16.031	+ 9.96	23.5
1.140	18	72	16.974	+ 7.68	21.5
1.149	19	76	17.917	+ 5.40	20
1.158	20	80	18.860	+ 3.12	18
1.167	21	84	19.803	— 0.84	15
1.176	22	88	20.746	— 4.44	12.5
1.186	23	92	21.689	— 8.03	10.5
1.196	24	96	22.632	—11.63	8
1.205	25	100	23.575	—15.23	6
1.215	26	104	24.518	—19.56	4
1.225	27	108	25.461	—24.43	1.5
1.236	28	112	26.404	—29.29	1″ vacuum.
1.246	29	116	27.347	—35.30	5″ "
1.257	30	120	28.290	—41.32	85″ "
1.268	31	......	29.233	—47.66	12″ "
1.279	32	......	30.176	—54.00	15″ "
1.290	33	......	31.119	—44.32	10″ "
1.302	34	.....	32.062	—34.66	4″ "
1.313	35	.....	33.	—25.00	1.5 pounds.

Size of Pipes in Brine Tank.

For general refrigeration about 120 to 150 running feet of 1¼ inch pipes are allowed for each ton of refrigerating capacity (in 24 hours) in brine tank. In case of ice making about 250 to 300 feet of 1¼ inch pipe is used in brine tank per ton of ice to be manufactured in 24 hours.

Rules for Laying Pipes for Brine.—Circulation.

The pipes in storage rooms should be placed where they are the least in the way. They should be arranged in independent

sections connected by manifold in such a way that each section can be shut out to throw off the frost. This can be done by introducing hot ammonia vapor (provision should be made to do this). For brine circulation as much as 200 square feet of piping is allowed per ton of refrigeration to be distributed; this of course depends on the temperature required, size and condition of room, insulation, etc. (See later on.)

Direct Expansion System.

In this system the expansion or evaporating coils are placed directly in rooms which are to be cooled, and the brine which is used as a medium in the brine system is dispensed with. The apparatus to circulate brine and the power to run same is thus saved. The difference in pressure between the delivery and return side of the ammonia compressor system being less than when the vaporization of liquid ammonia is affected in the brine tank coils, a higher efficiency is thus obtained. There is less expense in first cost and is simpler in operation.

Refrigerating plants that are continuously operated employ the direct expansion system almost exclusively. A direct expansion system consists of: (1) Compressor pump. (2) Condenser. (3) Complete system of piping.

Ice Plants. (Can System).

In Figure 4 is shown a sectional view of a freezing tank, disclosing the interior arrangement thereof, showing the arrangement of the ammonia evaporating pipes, ice moulds, frame work for holding the cans in position with wooden covers. Parallel rows of ammonia pipes with space between each set to admit a row of moulds being submerged in cold brine with which the tank is filled. The cans are filled with distilled water, the process of freezing being the same as explained in the brine system. The ammonia evaporating coils absorbing the heat from the brine and this in turn absorbs the heat from the water to be frozen. The time to freeze the water in the cans into solid blocks of ice is from 22 to 48 hours depending upon thickness of mould and temperature. The ice moulds are generally made in 50, 100, 200. 300 and 400 lb. sizes. The actual weight of the cake is about 10 per cent greater to allow for wastage. A suitable hoisting apparatus, such as block and tackle for smaller plants or a hoist attached to traveling crane for larger plants is provided for to remove the finished product. A thawing device to loosen the cake from the can is next in demand and consists of what is called a hot well or sprinkler. The cake so loosened will slide out of the mould and is ready for the market.

FIG. 4.

Plate Ice.

The plate ice system is especially adopted in some localities where water power is obtainable, as pure ice may be made by this method from portable water without being distilled. Water being taken from usual source of supply and when necessary thoroughly filtered and subjected to special treatment when required. In making ice in the plate system, hollow plates through which cold brine or ammonia vapor can be circulated, are placed vertically into a tank filled with water, and the ice forms gradually on both sides of these plates, thus purifying itself of any air or other impurities on its surface, which in the can system concentrate themselves towards the center, forming an impure core. This saves the process of distilling the water and therefore a saving of coal is effected by the plate system. On the other hand the latter system requires more skill to manipulate it successfully in all its details and the plant is more expensive to install and to keep in repair. The freezing on the plates to form ice of a thickness from about 12 to 14 inches takes from nine to fourteen days, forming cakes of ice weighing several tons. Plates are thus manufactured as large as 10x14 feet. When ice on the plates has become thick enough, hot ammonia vapor is taken from the system before it enters the condenser and is introduced into the coils, where it loosens the ice from the metal in a few minutes. The cake is then hoisted and cut up in blocks of suitable size.

In running an ice factory it is an important fact that the operation is a continuous one, that is to say day and night, in order to get the greatest production at the least possible cost.

Not only this, but the best conditions to insure the best quality and the greatest quantity should be observed and uniformly held. For instance, in drawing the ice it must be done with regularity, so many cans each hour, day and night, and the drawing uniformly distributed over the whole area of the tank. Cleanliness is the next important factor, filters should be occasionally steamed out, let nothing become foul and dirty about the distilling apparatus and change charge of filters whenever required.

An ice factory crew is generally divided into two watches of twelve hours each. For instance, in a 50 ton ice plant there would be one engineer, one fireman and two tankmen on each watch. The operating expenses are made up of the fuel, water, light, oil and waste, slight loss in chemicals, sundries and repairs, salary of superintendent, engineer and fireman, tankmen and other labor. It may be interesting to read what the cost of ice per ton will be in plants of different capacities. In Table III, the cost of ice per ton will be seen, the cost of ice decreasing as the capacity of the plant increases.

TABLE III.

ICE MANUFACTURE.

Approximate Cost of Operating Ice Factories.

Tons Ice per day.	Engineers $1 50 to $5 00 per day.		Oilers $1.25 per day.		Firemen $1.25 per day.		Tankmen and Laborers $1.00. per day.		General Helpers $1.25 per day.		Coal 15 cts. per cwt. or $3.00 per ton.		Oil Waste, Lights and Sundries.	Daily Operating Expenses.	Ice per ton.
1	2	$3 00		....		.. ....		....		....	500	$0 75	$0 50	$4 25	$4 25
2	3	3 00		....		....		....		....	1,000	1 50	50	5 00	2 50
4	2	3 00		....		....	1	$1 00		....	2,000	3 00	50	7 50	1 88
6	2	3 50		....		......	1	1 00		....	2,700	4 05	50	9 05	1 51
10	2	3 50		....		....	1	1 00		....	4,500	6 75	75	12 00	1 20
15	2	3 75		....		....	2	2 00		....	6,700	10 05	1 00	16 80	1 12
20	2	3 75		....		....	2	2 00		....	8,000	12 00	1 00	18 75	94
25	2	4 00		....	2	$2 50	2	2 00		....	8,400	12 60	1 10	22 20	89
30	2	4 00		....	2	2 50	2	2 00		....	9,500	14 25	1 25	24 00	80
35	2	4 00		....	2	2 50	2	2 00		....	10,800	16 20	1 50	26 20	75
40	2	4 50		....	2	2 50	3	3 00		....	11,500	17 25	1 75	29 00	73
50	1	2 75		....	2	2 50	4	4 00		....	14,300	21 45	2 00	34 45	69
60	2	5 00	1	$1 25	3	3 75	4	4 00		......	16,000	24 00	2 25	40 25	67
75	2	5 00	1	1 25	3	3 75	4	4 00	1	$1 25	20,000	30 00	3 00	48 25	65
100	2	5 00	2	2 50	4	5 00	6	6 00	1	1 25	25,000	37 50	4 00	61 75	62

In case of any extra or other expenses not mentioned in this table extra allowance must be made.

Distilling Water.

The water which is to be used for ice making should be free of all impurities; to gain this point, the exhaust steam is condensed after it has passed through a grease extractor where any oil or any other lubricating material used in cylinder of the engine is removed. The steam then passes into the steam condenser, which may be designed the same as the ammonia condenser, in which the steam is condensed to water and from there is passed to the skimming tank. Any impurity that may have passed the steam purifier is then entirely removed. The water resulting from the condensed steam passes to the reboiler, at the bottom of which is placed a small coil. The coil is supplied with a small quantity of live steam, which keeps it boiling, expelling all the air the water contains. The exhaust steam may not be sufficient to supply all the water needed so live steam must be introduced to supply the deficiency. From the reboiler the water passes to the cooling coil and from there to the filters. There should be at least one duplicate filter to facilitate cleaning.

The Compressor Pump.

The construction of the compressor pump is of vital importance, such as proper application and proportion of power by which it is driven. To effect a uniform motion and pressure, the cylinder and valves must be so designed to give free access to all

FIG. 5.

its parts and the clearance should be cut down to a minimum to expel or discharge all gas possible at each stroke, a well designed stuffing-box, perfect lubrication, etc.

Figure 4 shows a sectional view of a horizontal double acting cylinder. The gas enters at pipe A on top of the cylinder R R as receiving valves, D D are discharge valves, E being the dis-

FIG. 6.

charge pipe. Free access to the valves can be had by removing the caps C. The valves are so arranged to prevent undue clearance and discharge valves being at the bottom, can drain all liquid that might present itself in cylinder. The stuffing-box is

of considerable length, having an oil reservoir R, which is supplied by supply pipe S and overflows at pipe O. This secures perfect lubrication of the stuffing-box and also seals it to prevent the ammonia gas from escaping, or in other words, it assists the stuffing-box materially. The oil is supplied by a hand pump or automatically, as the case may be.

Figure 5 shows a vertical double acting compression cylinder in sectional view, called the De La Vergne. The gas enters through receiving pipe A into the receiving chamber, the receiving valves R and R1 are placed in pairs, one pair of discharge valves "D" are placed near the bottom of the cylinder, horizontal discharge valves D1 are placed on top of the loose cylinder head. The piston on its down stroke closes both discharge passages in succession, but as soon as it starts to close the bottom one, the top one communicates with the chamber in the piston (having a series of small valves, D). At the proper time when compression of the gas has commenced, refrigeration oil is injected in the cylinder alternately at A and A1 for cooling and to perfectly fill up the clearance and keep piston and rod in perfect lubrication.

The Eclipse Compressor.

Another type of vertical compression pump is the Eclipse. Figure 6 represents a sectional view of one of the cylinders. The steel suction valve of large area, is located in the piston, the gas inlet being at the base of the pump. The suction valve being balanced by a spring, presents upon the return stroke of the piston no resistance to the gas, which flows, under the back pressure, with considerable velocity into the vacant space above the piston. A cushion and spring assists in closing the suction valve and noiselessly as the up stroke is begun, the imprisoned gas being gradually compressed until it equals the condensing pressure acting upon the discharge valve, located in the pump dome, when discharge begins.

In order to make it perfectly safe to work the piston metal to metal against the cylinder head, the better to expel the full charge of the gas without danger, the pump head is made moveable or what may be called a safety head, it is simply a large valve the full size of the cylinder bore, through the seat of which the piston may pass without injury, raising the head before it sufficiently, in case some parts get loose, that no damage can ensue such as knocking out a cylinder head, which frequently happens in other constructions and thus losing the full charge of the gas. The safety head does not act as a valve, the real operating discharge valve is located in the center of the same. The safety head with its discharge valve may be removed, it being self contained, and

FIG. 7.

the whole valve mechanism may be replaced by a duplicate, or speedy repair may be made. This machine seems to gain great favor; it will be noticed that there is no clearance left between the piston and the discharge valve, which adds greatly to the efficiency of the machine. The compressed gas in double acting machines can not be all discharged on account of the unavoidable clearance; this compressed gas will expand back upon the return stroke and a full new charge of gas can not be obtained; the stuffing box is subjected only to the low pressure of the gas as it enters the cylinder, the pump being single acting, the compressing side is on the other side of the piston, therefore, the stuffing box is easily kept tight. The superheating of the gas is prevented in this machine by a water jacket which is continuously supplied with cool water. Figure 7 shows us a sectional view of Eclipse machine with two single acting compressure pumps placed side by side, driven by a horizontal Corliss engine.

FIG. 8.

The Condenser.

The condenser consists of a series of pipes into which the compressed ammonia gas is forced by the compressor pump. The office of the condenser is to condense the ammonia gas as it is discharged from the compressors, and the work done in the condenser is the taking up of the latent heat of vaporization, plus part of the heat generated by compression. There are several styles of condensers, the open air condenser (atmospheric), which is generally placed on the roof or on such a place where constant current of air can strike it, if possible; the cooling water trickles over the pipes; the Ammonia vapor flows in opposite direction, entering at the bottom of the condenser, the condensation passing off to the side into a vertical manifold as fast as condensation takes place. The amount of condensing surface for an atmospheric condenser is about forty square feet per ton of refrigerating capacity or for one half ton of ice making capacity. This is equal to 64 linear feet of 2 inch pipe or 90 feet of 1¼ inch pipe.

The submerged condenser consists of one or more sections of coils of 1¼ to 2 inch pipe. There should be a number of coils, each connected by manifolds at the inlet and outlet in such a manner that one or more can be shut off to be able to make repairs, or for other reasons. The size of pipe at the outlet may be smaller than that at the inlet for the ammonia vapor, for instance the pipe at the inlet is 2 inches, it may taper down to 1 inch at the outlet, where the ammonia is more or less liquified, therefore occupying a smaller space. The ammonia is a submerged condenser enters at the top and liquid ammonia leaves at the bottom. The coils being suspended in a tank which contains the cooling water, which enters at the bottom and as it absorbs the heat of the ammonia becomes warmer and overflows at the top. The economical working of the machine depends largely on the efficiency of the condenser and it is, therefore, good policy to have as much condenser surface as practical consideration will permit. In practice it has been found that for average conditions (the incoming condensing water being 70° and the outgoing 80°, more or less) for each ton of refrigerating capacity (or one-half ton ice making capacity) it will take 40 square feet of condenser surface, which will be as before stated 64 linear feet of 2 inch and 90 linear feet of 1¼ inch pipe. In some cases 20 and even less condensing surface is allowed, but this means higher condenser pressure, and therefore, is poor economy.

The following tables, compiled by Skinkle, give the dimensions of both atmospheric and submerged condensers of plants in actual use, and it will be seen that much more pipe for the atmospheric than for the submerged condensers is allowed. On the highest part of the condenser a purge valve should be placed to let off permanent gases.

TABLE IV.

ATMOSPHERIC CONDENSERS.

Ice making Capacity in Tons.	Refrigeration Capacity in Tons.	CONDENSER PANS.				Number of Pipes High.	Number of Pipes Wide.	Size of Pipes in Inches.	Length of Coil Overbents in feet.	Total Feet of Pipe in Condenser.	Feet of Pipe per Ton Ice Making Capacity.	Feet of Pipe per Ton Refrigerating Capacity.
		Length of Pan in Feet.	Width of Pan in Feet.	Depth of Pan in Inches.	Thickness of Iron in Inches.							
12½	25	21	10⅔	8	3/16	40	5	1	17	3,680	294.4	147.2
20	35	24½	10⅔	8	3/16	40	5	1	21	4,440	222.	126.8
30	50	24½	14	8	3/16	50	7	1	21	7,750	258.3	155.
40	75	24½	14	8	3/16	50	7	1¼	21	7,750	193.75	103.33
50	100	24½	14	8	3/16	90	7	1	21	13,950	279.	139.5
60	125	24½	14	12	3/16	80	7	1¼	21	12,400	206.6	99.2
80	150	27½	17	12	3/16	80	7	1¼	24	14,080	176.	93 86
Average for 1 inch pipe, per ton											283.42	142.12
Average for 1¼ inch pipe, per ton											192.12	98.79

TABLE V.

SUBMERGED CONDENSERS.

Ice Making Capacity in Tons.	Refrigerating Capacity in Tons.	TANKS.				Number of Coils.	Pipes High.	Feet Long.	Size of Pipe in Inches.	Total feet of Pipe in Condenser.	Feet of Pipe per Ton Ice Making Capacity.	Feet of Pipe per Ton Refrigerating Capacity.
		Length in Feet.	Width in Feet.	Depth in Feet.	Thickness of Iron in Inches.							
5	10	10	3⅓	6½	3/16	9	12	7½	1	.855	171.	85.5
10	20	10	7½	6½	3/16	20	12	7½	1	1.900	190.	95.
12½	25	10	7½	6½	3/16	22	12	7½	1	2.090	167.	83.6
15	30	10	8⅓	6½	3/16	25	12	7½	1	2.375	151.6	79.16
20	35	10	10	6½	3/16	27	12	7½	1	2.565	128.25	73.28
30	50	10	10	12½	1/4	27	24	7½	1	5.130	171.	102.6
40	75	14	10	13½	3/8	27	24	11½	1	7.695	191.1	102.6
60	110	14	13	13½	3/8	35	24	11½	1	9.975	166.25	90.68
Average											167.	89.

Fore Cooler.

Sometimes a fore cooler is used before the ammonia vapor reaches the condenser to assist the latter in its work. The fore cooler is cooled by spend or overflow water of the condenser. It consists of one coil, which should have the same size at the discharge pipe of the compressor. If it consists of a number of coils, the manifold pipe and the area of the opening of the small pipes must be equal to that of the discharge pipe.

The Ammonia Reservoir.

The ammonia liquid as it leaves the condenser is collected by a receiving tank; it is placed between the condenser and expansion valve. It is made cylinder shape and holding about one-half gallon for each ton of refrigerating capacity (in 24 hours) of the machine. It also serves as an additional oil-trap, the oil being heavier than the ammonia, causes it to settle at the bottom and can be drawn off by means of a valve provided for this purpose. (See Figure 9.)

FIG. 10.

The Expansion Valve.

The expansion valve is placed between the liquid receiver and the expansion coils, by means of which the attendant is enabled to regulate the flow of ammonia. (See Figure 10.)

FIG. 9.

The Freezing Tank.

The size and length of the pipes in the brine tank should be arranged in such a way that each row of moulds is passed by an ammonia pipe on each side; the wide side is preferable. The series of pipes are connected by manifolds. The liquid ammonia entering the manifold at the lower extremity and vapor leaves by the suction manifold at the higher extremity of the coils. Brine tanks are made of sheet iron, steel, wood or cement. Tank steel is said to make the best tanks. If properly built, they last from ten to twelve years. The freezing tank should be no larger than is required to receive the moulds, the freezing coils and the agitator. Two inches space may be left between the moulds and three inches where the pipes pass between them; three additional feet may be allowed to the length of tank for the agitator, otherwise the size depends on the size of the moulds, that is, the time it takes to freeze the contents solid. If it takes 48 hours to close the cans the freezing tank must hold twice as much as is expected to be turned out in 24 hours. The brine agitator consists of a small propeller wheel, not unlike those we see on steamboats; it is driven by a belt and keeps the brine in constant motion from one end to the other.

Amount of Piping for Cold Storage.

The amount of piping necessary for refrigeration in cold storage houses depends entirely on temperature to be kept, the insulation of the buildings, nature of the business, etc. It is impossible to arrange a table that would fit any and all cases.

There is, however, for each storage temperature a preferable temperature for direct expansion and brine circulation, and the following tables on piping are expected to fit this temperature for practical calculations:

The following tables refer to the direct expansion; for brine circulation there should be from one and one-half to two times the length of the former. This table shows the number of 1 inch pipe needed per cubic foot. To find the number of 1¼ inch pipe, divide the length by 1.25 or multiply 0.8, which will give you the corresponding number of feet in 1¼ inch pipe. The next table will show the number of cubic feet of cold storage that will be covered by 1 foot of 1 inch pipe during a period of 24 hours for different size rooms and different temperatures.

TABLE VI.

LINEAR FEET OF ONE INCH PIPE REQUIRED PER CUBIC FOOT OF COLD STORAGE SPACE.

Size of Building in Cubic Feet more or less.	Insulations.	TEMPERATURE °F.					
		0°	10°	20°	30°	40°	50°
100	Excellent	3.0	0.78	0.48	0.36	0.24	0.15
	Poor	6.0	1.50	0.90	0.66	0.48	0.30
1,000	Excellent	1.0	0.27	0.16	0.12	0.08	0.05
	Poor	2.0	0.50	0.30	0.22	0.16	0.10
10,000	Excellent	0.61	0.16	0.10	0 075	0.055	0.035
	Poor	1.2	0.33	0.20	1.15	0.11	0.07
30,000	Excellent	0.5	0.13	0.08	0.06	0.040	0.025
	Poor	1.	0.25	0.15	0.11	0.03	0.05
100,000	Excellent	0.38	0.10	0.06	0.045	0.03	0.009
	Poor	0.75	0.20	0.12	0.09	0.06	0.018

TABLE VII.

NUMBER OF CUBIC FEET COVERED BY ONE FOOT OF ONE INCH IRON PIPE.

Size of Building in Cubic Feet more or less.	Insulations.	TEMPERATURE °F.					
		0°	10°	20°	30°	40°	50°
100	Excellent	0.3	1.3	2.1	2.8	4.2	7.0
	Poor	0.15	0.7	1.1	1.5	2.1	3.5
1,000	Excellent	1.0	4.	6.0	8.4	12.4	20.
	Poor	0.5	2.	3.2	4.5	6.2	10.
10,000	Excellent	1.7	6.	10.	13.	18.	28.
	Poor	0.85	3.	5.	6.5	9.	14.
30,000	Excellent	2.0	8.	14.	18.	25.	40.
	Poor	1.0	4.	7.	9.	13.	20.
100,000	Excellent	2.6	10.	17.	22.	13.	110.
	Poor	1.3	5.	8.5	11.	17.	55.

This also refers to direct expansion and only one-half or two-thirds of this space will be covered in case of brine circulation by one linear foot of 2 inch pipe. In case 1¼ inch pipe is used, the numbers in the table have to be multiplied by 1.25 or divided by 0.8. To find the corresponding number of the numbers in Table it must be multiplied by 1.8 or divided by 0.55. In the foregoing tables it will be noticed that the insulation of the building is the next important feature in refrigeration. (See chapter on insulation.) More frequently in piping the rooms, a rule is followed

which by experience was found to do the work, or in other words, a certain number of feet of pipe will cover a certain number of cubic feet of space. For instance in breweries it is assumed that one square foot of pipe surface will cool about 40 cubic feet of space in fermenting rooms and about 60 to 80 cubic feet in shr and chip cask cellar. (Direct expansion.) For brine circulation about one-half this space will be cooled.

In packing houses it is assumed that one linear foot of 2 inch pipe is sufficient for 13 to 14 cubic feet of space in chilling rooms, direct expansion, and from 7 to 8 cubic feet for brine circulation; and for storage room, one linear foot of 2 inch pipe is allowed for 45 to 50 cubic feet of space for direct expansion, and from fifteen to eighteen cubic feet of space for brine circulation. For freezing rooms, 1 linear foot of 2 inch pipe for 6 to 10 cubic feet of space for direct expansion, and 3 cubic feet of space in case of brine circulation.

Care and Management of a Plant.

Before starting up a new plant it must be minutely inspected and tested, especially the piping. Owing to the nature of the ammonia and the high pressure it is subjected to, a test must be made to prove the whole system air tight, before charging the system with the ammonia. This is done by subjecting the whole system to an air pressure of 300 pounds to square inch, by working the compressor and opening up the suction valves provided for this purpose. When the gauge shows the 300 pound mark, the leaks if any should be present, can be detected by applying thick soap lather to the joints of the pipes and other suspicious places, and if any leaks are present soap bubbles will be formed in the brine tank and also on the condensing (if submerged) bubbles will rise in the water. If all joints are tight and pressure and temperature is equalized over the whole system, the pressure gauge should remain stationary, if everything is absolutely air tight. After the system was subjected to an internal pressure the air is discharged, the compressor is started again and all the air is exhausted by opening the proper valve and this way pump a vacuum. When the vacuum is obtained the pump is stopped and all outlets are closed. The system now is subjected to an external pressure and if everything is tight the vacuum gauge will remain stationary.

Charging the Plant.

After the plant has proved to be air tight, it is charged with ammonia in the following manner: The vessel that contains the ammonia is connected to the charging valve. The expansion valve between the receiver and expansion coils is closed before the valve on the ammonia flask is opened, the compressor is started

up and run very slowly with suction and discharge valves open and water is running on the condenser. If any air is present or in other words the vacuum was not perfect, the system should be charged by degrees, only about half of the ammonia which is necessary to charge the plant should be introduced and after this has been circulated in the system, most of the air that is present will collect at the top part of the condenser, where it may be discharged or blown out by a valve called the purge valve. The balance of the ammonia is then introduced in a similar way in one or two installments. The amount of ammonia a plant is charged with is generally one-third pound for every linear foot of 2-inch pipe (or its equivalent) in expansion coils. According to this a plant of 25 tons ice making capacity which has about 5000 linear feet of 2-inch pipe would require about $\frac{5000}{3}$=1,666 lbs of ammonia, and a direct expansion plant which has about 2000 linear feet of pipe about $\frac{2000}{3}$=666 lbs., or say 700 in round numbers. In case of brine circulation and a machine of the same capacity it would require only 275 pounds of ammonia. Giving this in the rate per ton, it would take 66 pounds per ton for ice making; 26 pounds per ton for direct expansion; 12 lbs per ton in brine circulation.

Waste of Ammonia.

As before stated the ammonia is evaporated, compressed, condensed and evaporated, again forming a complete cycle. Theoretically speaking there should be no waste of ammonia, but in practice anhydrous ammonia will wear away in course of time. This is largely due to leakage and partly to decomposition. The amount lost depends entirely on the care the plant receives. In a plant of 25 tons capacity it is estimated that from 50 to 100 lbs of ammonia will be lost per year, which can not be avoided, although the loss may run all the way up to 200 pounds. Decomposition can be largely avoided by keeping the temperature around the compressor as low as possible. When the ammonia runs low it can be readily detected by the gauge glass on the liquid receiver, it also can be noticed on valves of the compressor, sometimes they work smooth and easy and again hard and noisy, showing that the supply of ammonia is insufficient, etc.

Mending Leaks.

If any smell of ammonia is detected in any part of the system, it is due to leaks and must be mended without delay. Small leaks may be closed by soldering up with tin solder. A soldering fluid suitable for this purpose is prepared as follows: Dissolve as much zinc in a certain quantity of muriatic acid as it will take; ascertain as near as possible the weight of zinc, an equal amount of chloride of ammonia or salmoniac is then added to the solution of zinc and muriatic acid. This will cleanse the iron sufficiently before applying the solder.

If the leak is too large to be mended in this way a new section of pipe must be inserted. To make a temporary repair a cement is used which consists of litharge mixed with glycerine to a stiff paste, this cement when applied must be covered with sheet rubber held in position by iron clamps which are made for such purposes.

Clearance Marks.

The clearance in the compressor pump between piston and piston head is very small; it should never exceed 1/32 of an inch, and as wearing of the brasses in the connecting rod makes tightening necessary, the clearance will therefore be changed the same as it would be in an engine. It is very important to have the clearance equal on both sides for this reason. The gas which has been compressed and is not discharged will expand back and fill up part of the space, which otherwise would receive a fresh charge and it will be seen that this side which has the least clearance will discharge the most gas, in otherwords, one side would discharge more gas than the other. This can be avoided by making clearance marks on the cross-head guides, which will show the clearance on the outside of the cylinder.

Cleaning of Condenser.

Condensers which have been running for a length of time, have a tendency to become incrusted from deposit by the water which trickles over them. This should be removed from time to time, and should be subjected to water pressure of about 300 to 350 pounds to discover any corrosion, which might have taken place.

Cleaning of Coils from Oil.

It frequently happens that the system or the interior inner-surface of the pipes become coated with oil, which by escaping the oil-traps deposits itself on the inner surface of the expansion coils. Oil is a poor conductor of heat and in great messure effects the efficiency of the plant. This can be removed by run-

ning hot ammonia vapors through those coils; this warms and liquifies the oil and is then mixed with the ammonia drawn into the compressor and from there to the oil-trap where it is separated from the ammonia. This way of cleaning is claimed to be very effective if done often, say every week.

Insulation of Pipes.

The insulation of the pipes running from the compressor to condenser, and from condenser to expansion coils is very important; this can not be done too well.

The same applies to brine tank and freezing tank.

Lubrication.

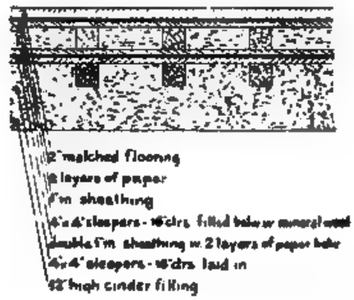
The oil that is necessary for lubricating the compressor must not congeal in low temperatures and must be free from vegetable and animal oils, only mineral oils can be used and only such that will not freeze in low temperatures. Regular cylinder oil should be used for the steam cylinder and free flowing oil for all bearings and other wearing surfaces. For heavy bearings on ice machine a heavy oil should be used, while small bearings should be lubricated with a very light oil to avoid undue friction.

Insulation of Buildings.

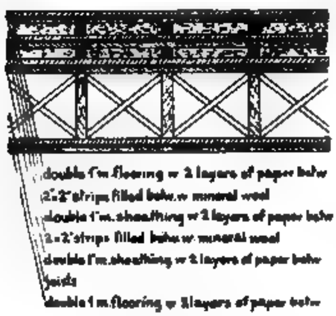
After refrigerating plant is installed the next thing to be considered is the proper insulation of the storage room. If it were possible to keep the heat outside of the rooms from penetrating the walls of the same, one cooling operation would be sufficient to keep the room at the same low temperature for an indefinite period of time. But such conditions are impossible; therefore it becomes necessary to construct the cooling rooms with the most perfect insulation possible in order to avoid the employment of a large surplus of refrigerating power to take care of the negative heat. Poor and cheap insulation is false economy, since a large percentage of the actual work of the refrigerating plant is required to make up for the passage of heat through the walls, floors and ceilings, caused by poor insulation; therefore it may be safely said that in this case the best is the cheapest. In the following figures the styles of insulation for different buildings are given, which were found to be quite effective:

double 1"m flooring w 2 layers of paper betw

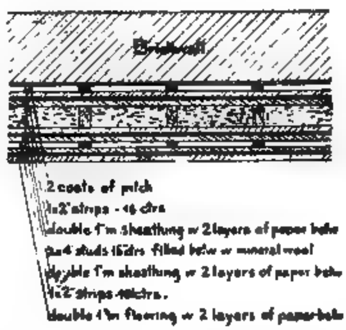
nsulation of walls built of wood



Insulation of groundfloor.



Insulation of ceilings for wood construction.



Wooden insulation for brickwall.

cement plaster.

Insulation of walls for fireproof buildings.

Insulation of ceilings for fireproof buildings

HYDRAULIC ELEVATORS

The mechanism of Hydraulic Elevators is very simple, as is also the principal upon which they operate. The mechanism consists of a cylinder and piston and suitable valves for controlling the flow of the water so as to cause the piston to move from one end to the other and back again. The motion is transmitted to the crosshead by means of one or more rods, that in turn are connected to the lifting ropes from which the elevator car is suspended. The cylinder may be placed either horizontally or in vertical position, the elevator car may move with the same velocity as the piston or several times faster, however, in most cases the motion of the piston is multiplied so that the car moves from 2 to 10 and even as much as 12 times faster than the piston. Where floor space is restricted vertical machines are used and if the space required for a vertical machine on the floor above cannot be spared, a horizontal machine is installed. Where floor space is not a matter of importance either machine may be used. The type of machine is entirely a matter of individual choice.

Direct Connected Elevator.

The simplest kind of Hydraulic elevator is the direct connected, which is illustrated in Figure 1. The plunger or ram is placed directly under the platform, the cylinder is sunk into the floor so as to allow the platform to descend level with the floor. The valve that regulates the flow of water, is operated by a shifting rope placed on two sheaves. The platform is started upward by pulling the rope nearest to the guide and is stopped automatically by means of a chain which is connected with the rope at one end and the other end passing through a hole in the car and is held in position by a ring. Before the car or platform arrives at its extreme upper end, the chain is pulled tight which causes the shifting rope to follow, this causes the sheaves to rotate, closing the valves. This same chain is used to start the platform downward by simply pulling the chain up, this releases the water and the platform descends as fast as the ram or plunger can force the water out of the cylinder. In this arrangement, the cylinder must be equal in length to that of the travel of the platform which would not be practical in elevators of longer travel. The use of this class of elevators is restricted to short travel only, say from one floor to the floor above. In elevators of longer

travel some means must be employed to increase the speed of the car so that the latter moves through a distance several times that of the piston. To accomplish this the hoisting cable is passed over one or more sheaves; whether horizontal or vertical machine the principle remains the same.

Horizontal Machines.

In horizontal machines the ratio is seldom less than 6 to 1, that is, the car will travel 6 feet while the piston moves 1 foot.

FIG. 1.

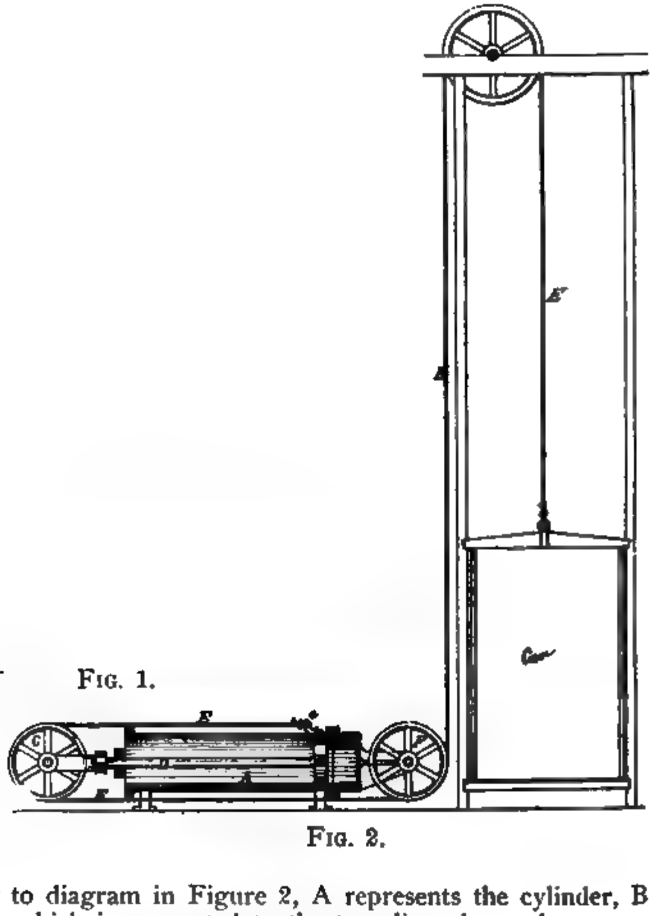


FIG. 2.

Referring to diagram in Figure 2, A represents the cylinder, B the piston which is connected to the traveling sheave by means of the rod D. The stationary sheave F is located at the back end of the cylinder, supported by a bracket fastened to the cylinder

head. Following the rope E from the point e where it is securely fastened it passes over the traveling sheave C then back and around the stationary sheave F, then up and around the two overhead sheaves and down again, connecting with the top of the car.

It will be seen that the traveling sheave C when at the end of its travel has taken up twice as much rope as is due to its travel. One end being securely fastened at e, a stationary point, the other end that is fastened to the car must therefore travel twice as fast or equal to two times the distance the piston has traveled; this gear ratio is called 2 to 1. In a 4 to 1 ratio an additional sheave is placed at each end alongside the first one and the rope is passed around once more before passing up to the overhead sheaves. An additional sheave is required at each end for each higher ratio and if two or more hoisting cables are used it requires a set of sheaves for each rope.

Rope Arrangement for Vertical Machines.

In a vertical machine the rope arrangement slightly differs from that of the horizontal type. In a horizontal machine the piston is pushing the traveling sheave before it, while in vertical machines the piston is put in pulling position but the principle remains the same, as will be seen in diagram Figure 3 with a gear ratio of 2 to 1. In this construction one end of the rope is fastened to a stationary point above the traveling sheave, passing down and around the latter, then up and over the two overhead sheaves, then down again connecting with the car, thus when the piston moves, say 10 feet, the car must move twenty. In a 3 to 1 gear an additional sheave is placed in a stationary position as shown in Figure 4. The rope passes over this, connecting with the top of the trap that holds the traveling sheave. In a 4 to 1 ratio another sheave is connected to the traveling sheave as shown in Figure 5, the rope passes around this and is then fastened to a stationary point, the same as in the two to one ratio. In Figures 6 and 7 the arrangement of the ropes of a 5 to 1 and 6 to 1 gear ratio is plainly shown.

Valves for Controlling the Water in Hydraulic Elevator Machines.

In slow speed elevators that travel from 100 to about 250 feet per minute the construction of the valve is very simple, but in our modern high speed elevators this simplicity can not be retained for the following reasons: The valves that control the flow of the water to and from the cylinders vary in size from 3″ in small machines up to 7″ and 8″ in machines of the larger sizes.

To keep such valves tight a cup-shaped packing is used. The water under considerable pressure expands this packing out against the walls of the valve chamber making a watertight joint, but at the same time adds greatly to its friction and considerable force is necessary to move such valves, ranging from about 40 pounds in smaller machines up to about 150 pounds in larger ones. In slow speed elevators where the hand rope is used to control the valve, the pull on the rope may be greatly reduced by making the connection; see that the hand rope is pulled through a distance of several feet, while the valve only moves a few inches. In modern high speed elevators which travel from 250 to 300 feet per minute and over, the hand rope if used would slip through the operator's hand with velocity of 5 or more feet per second; this would make it very difficult for the operator to grip

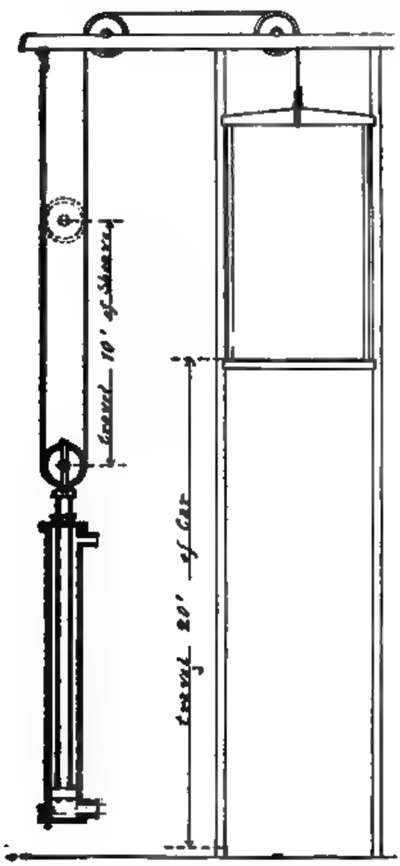


FIG. 3. FIG. 4. FIG. 5.

the rope at the proper time, a fraction of a second too soon or too late would cause the car to stop either above or below the point desired. To do away with this uncertainty of operation, lever and wheel devices have been applied, but to make these devices operate, the valve has been modified also.

FIG. 6. FIG. 7.

Automatic and Auxiliary Valve for Hydraulic Passenger Elevators.

Figure 8 represents a valve partly in section that is used in connection with the Crane horizontal hydraulic passenger machine. The controlling valve proper consists of the two plunger heads A and B; the smaller plunger L somewhat balances A, if water under pressure is admitted at D, which is the inlet, the head A, which is larger than L will move to the right, but if

water under the same pressure is admitted into cylinder I, the valve will move to the left under a pressure that is due to the difference in area of A and L, the piston in the cylinder I being of the same diameter as A. The small auxiliary or pilot valve G is connected to J by means of valve rod N; this rod receives the full motion of operating cable, which in turn receives its motion from the lever in the car. E is the discharge outlet and the opening F connects with cylinder. The operation of this valve is as follows: To start the car up, the attachment J is pushed

FIG. 8.

to the right, this causes pilot valve G to uncover port c, the water in cylinder I that held the valve to its central position passes through port c into port e into the discharge chamber. This releases the pressure in cylinder I and the valve moves to the right. Plunger head A being moved past the central opening, the water in D can pass through and out of F into the cylinder. To start the car down the attachment J is pulled to the left, this causes pilot valve G to follow and uncovers port c so that the latter is in communication with the pilot valve chest which is in connection with the pressure pipe through pipe H. Water under pressure can now enter into cylinder I, and owing to the difference in area of the piston and L, the valve is forced to the right, this movement of the valve places plunger head B

FIG. 9.

to the left of the central opening and F is put in communication with discharge E, allowing the water in the cylinder to pass through F into the discharge E. The screw k, which is placed into port e, is for the purpose to regulate the flow of water when passing out of cylinder I; by this means the pressure in cylinder I is released more gradually, which otherwise would cause a shock to car when a stop is made by going down, the valves would close up too suddenly.

If a slow motion of the car is desired by either going up or down, the pilot valve is only partly opened, for instance by going up push J, is moved to the right, just enough to open the port c partly so that the water in cylinder I can escape; this causes the valve to follow slowly, pulling at the same time on the long lever arm O to which it is connceted. This lever O consists of a long and short lever arm swinging on fulcrum P. Valve rod N connected to the short lever arm will move to the left while the valve is moving to the right, thereby closing the pilot valve automatically; this closing of the pilot valve will stop the flow of water from the cylinder I, arresting piston m, leave the valve only partly open; the water can not enter into the cylinder as through a full opening, with the result that car moves slowly.

The stop valve M is opened and closed automatically as the car starts from the top or bottom landing, giving a free flow of water from the cylinder. As the car reaches the upper or lower landing the valve is automatically closed so that the car stops gradually and without a shock at both terminals.

Plain Rack-Valve.

The plain rack-valve is operated by a hand rope which passes over a sheave that together with a pinion is mounted upon the same shaft, the pinion engages with a rack, as shown in Figure 9. This valve is shown in connection with a vertical machine, but the construction varies little from that used in horizontal machines. In vertical machines the pressure is always at the upper part of the cylinder. Referring to Figure 9, the operation is as follows: As represented in the cut the piston is at the lower end of the cylinder, which means that the car is at the top landing; to start the car down the sheave A is turned in a direction opposite from that of the hands of a clock, the pinion that engages the rack moves the valve B from its central position downward and opens up communication between the ends of the cylinder. The weight of the car acts to move the piston upward, forcing the water that is on top of the piston D, in cylinder C, into pipe E, past the valve B into the lower part of the cylinder. To start the car up, the sheave A is rotated

in a clockwise direction, and valve B is moved up so that it opens up communication between the lower part of the cylinder and the discharge pipe. As the water escapes from the cylinder below the piston the pressure that is on above forces the piston down again, assisted by the vacuum that is created by the vacating water below. Pipe E is called the circulating pipe, the supply pipe may be connected at any place on the circulating pipe E between valve and upper T or at the valve between valve B and balance piston F. The valve G is for the purpose of relieving the piston of some of the water if valve B is suddenly closed, which otherwise would cause a shock, as the water is not compressable.

The foregoing represents the Otis vertical machine for passenger and freight service.

Otis Differential and Auxiliary Valve.

The valve represented in Figure 10 is built after the principle of the valve in Figure 8, the purpose of which is to use the pressure of the water for moving the valve. This valve in connection with a vertical machine operates as follows: As will be seen, piston A is larger in diameter than valve B, therefore if water under pressure is admitted into the space between A and B, the excess of pressure on piston A over that of the upper part of valve B will carry it upward, provided there is no pressure on the upper side of piston A. If water under the same pressure be admitted on top as well as under it the piston A would be balanced and remain stationary were it not for valve B which is on its under side exposed to atmospheric pressure only, or that of the discharge tank, therefore the valve under this condition will be depressed.

The small pilot valve C is placed in valve chamber D. This valve chamber communicates with pressure pipe through E and with the space above piston A through pipe F, another pipe G leads to the discharge pipe. When the elevator is at rest, the pilot valve C is in position to cover the ports that connect pipe E and F and also prevents water from escaping from pipe F into G. When the sheave H is rotated in a clockwise direction the crank on the end of the shaft draws down the connecting rod I and as the small pilot valve moves much easier then the main valve B and piston A the latter will remain stationary, and the pilot valve C will be depressed. This movement of the pilot valve uncovers the port that connects pipe F and E and water under pressure will flow from the pressure pipe through E and F into the space above piston A and force the latter downward. This downward movement will move the main valve B far enough to uncover the port that connects with the lower

end of the cylinder, thus opening up communication between the two ends of the cylinder. The water on top of the piston can now circulate to the lower part of the cylinder as explained in Figure 9. This action takes place when the car descends; to

FIG. 10.

run the car up, sheave H is rotated counter-clockwise, the crank on the shaft pushes the connecting rod I upward and by means of rod J the pilot valve follows. This movement of the latter uncovers the port that connects with pipe F, but keeps the port

that connects with E closed so that the water which has been confined in the space above piston A can escape through pipe F and G into the discharge pipe. The pressure on the upper side of the piston A being removed the pressure on the lower side forces the valve up owing to the difference in area of piston A and valve B. This latter movement of valve B opens up communication between the lower end of the cylinder and the discharge pipe, and the water in the cylinder can pass through to the discharge tank as the car is going up.

Sometimes it is desired to run the car slow, this may be accomplished by rotating the sheave H to only such an extent that the pilot valve only partly opens the ports that connect the pipes E and F by going down for instance. When the valve B starts to move downward the valve rod that is connected with the long lever arm K will also move down; connecting rod I being now stationary the short lever arm to which the pilot valve is connected by means of rod J will move up and close the ports that connect pipes E and F. The moment these ports are closed the valve B stops, but the port is only partly opened so that the water can circulate but slowly, consequently a slow movement of the car.

Arrangement of the Ropes in Connection With a Lever that Operates the Valve.

The motion of the lever in the car, in the hands of the operator, is transferred to the valve by means of a wire rope or cable. There are two systems in use: the running rope—and the stationary rope system. In Figure 11 the arrangement of the stationary rope system is shown; the lever S is placed inside of the car in such a position that the operator may have the lever and gates within easy reach. This lever is mounted upon a shaft below the car; upon this shaft is mounted a rocker; upon the ends of this rocker the sheaves P and Q are placed; the rocker is placed in such a way that the ropes which must pass over these sheaves are on the outside of the car. Each one of the sheaves is provided with a double groove so that each cable may pass from one side to the other. Following the rope on the side o it passes down and under sheave P, then over Q, then down and under sheave O, then over sheave N, then back to sheave M, then up and over sheave P, then under sheave Q, then up to m, where both ends are fastened to lever R. This lever is sufficiently weighted on its long arm to keep the ropes always in proper tension. Now if this lever is thrown either over one or the other direction, one of the ropes will be shortened while the other will be elongated; this motion is transferred to the sheave N, which in turn operates the valve.

In the running rope system two small sheaves are mounted upon a larger one; one set is placed at the bottom of the elevator shaft, while the other set, which is mounted upon a bar, is placed above the limit of travel as shown in Figure 12. The lever is mounted upon a shaft below the car as in the stationary rope system. The ends of the rope are fastened to the ends of the rocker arm, which is also mounted on the lever shaft. Following the rope from the point a it passes down and around sheave c, then up and over sheave f, then down again where

FIG. 11.

FIG. 12.

it is connected with the rocker at b. Then following the rope from the point b it passes down and under sheave d, then up over sheave e, then down again to the rocker connecting at the point a. The large sheave G is connected to sheave H by means of the rope h. The upper set of sheaves is suspended by rope which passes over one or more sheaves to the outside of the elevator shaft with a weight attached sufficiently heavy to keep the controlling ropes in proper tension. By throwing the lever L to one side of the rope it will be shortened while the other will be elongated, this causes the sheave G to rotate, this sheave transfers the motion to sheave H by means of rope h. In both systems there are several modifications but they all accomplish the same result, namely, to transfer the motion of lever L to sheave H.

Automatic Stopping Devices.

When the hand rope in connection with the plain rack-valve is in use, either on vertical or horizontal machines, stop buttons are fastened to the hand rope. The car or some attachment on the latter through which the rope slides will strike one of these buttons a little before the car reaches the top or bottom landing, thereby causing the rope to move along with the car, this causes the sheave on the valve to rotate and valve is closed gradually.

In the lever arrangement an independent device is necessary.

Referring to Figure 12, a gear wheel is mounted upon the shaft that carries the rotary valve 1, this gear wheel meshes with a smaller gear mounted upon the same shaft with the sheave 2, around which the rope 3 passes. This rope is provided with stop buttons which are struck by the arm 4 that is attached to the crosshead a little before the car arrives at its lower or top landing, closing the valve automatically.

Safety Devices.

The safety device is for the purpose of stopping the car if from any cause it should run away; this may be caused by the breaking of the lifting cables, or springing of a leak in the pressure pipe, etc. There are many of these safety devices in use and one of the best ones is shown in Figure 13, called the Hale safety device. The automatic governor A is located on the overhead beam on top of the elevator shaft, and is operated by an endless rope that passes over its driving sheave, and over another one, B, at the bottom end of the elevator shaft. This sheave is mounted upon a frame which is sufficiently weighted to keep the rope in a uniform tension. The ends of the rope are connected to the lever C, which acts upon a lever mounted on

FIG. 13.

the shaft that operates the gravity wedges on both sides by means of the lever D. Now if the car should for any cause reach a dangerous speed the hook shaped dogs, which are held in position by springs on the governor wheel, will fly out and strike a projection on the bottom of the frame upon which it is mounted, this causes a jerk upward on the rope and lever, and by means of its connection with the gravity wedges will force the latter up and grip the guides on both sides of the car so that it will come to a stop; this device is shown in an enlarged scale in Figure 14. Under the gravity wedges is a rocker arm or

FIG. 14.

equalizing bar, to which the lifting cables are attached independently at each end; the cables so attached pass over a wrought iron girdle at the top of the car. Each cable carries an equal strain, the breaking of one would throw the load upon the cther, and throw the equalizing bar out of equilibrium. As represented, the cable B has given away and the load being thrown on A causes the adjusting screw c to strike lever C, which in turn forces up the wedge D. The lever C is keyed upon a shaft E which reaches clear across the bottom of the car with a lever to act upon the wedge on the other side of the car so that the wedges on both sides are forced up, and form a tight grip on the guides. The car so stopped can not be lowered but may be hoisted when the cause of the trouble is removed. This device will also give warning before hand; any cable will stretch before breaking, this throws the equalizing bar out of equilibrium more or less and this will cause jerks by descending if not actually stopping the car.

Racking the Piston of a Horizontal Hydraulic Cylinder.

In horizontal cylinders the stationary sheaves are mounted upon the back end of the cylinder, therefore the piston can only be packed from the front end. The car must therefore be run within one foot of the top and securely fastened there. This being done all the water is drained out of the cylinder by closing the valve on the pressure pipe, opening of the air valve on top and the drain cock below the cylinder. The water being all drained we remove the first buffer across the front end of the cylinder and slide it out of the way along the piston rod. Next we remove the follower, and the old packing, which is best removed by means of a packing-pull, such as is used to remove the packing from the stuffing box of an engine. If the cylinder is in good condition 4 rings of 1 inch square lubricated fibrous packing may be used; this packing is cut 9 inches longer than the inside circumference of the piston. These rings are best inserted by holding the ends of a ring together and form tugs with the balance which may then be forced in with a hardwood stick, one after another, until level against the piston head, taking care that they do not come together; however, before this is done the piston must be raised so that it is central with the cylinder. If the cylinder should be badly worn it is advisable to use a square rubber packing for the first and last ring, cutting the rubber rings only 1 inch longer than the circumference of the cylinder; this rubber forms a backing for the fibrous packing.

When the packing is in position we replace the follower, screwing the nuts up by hand until the follower rests against the packing, then we screw the two jamb nuts which are placed opposite each other out against the follower and tighten with a wrench; next we replace the buffer and screw it up tight. Now the cylinder is ready to be filled; we place the valve in position for going up, close the drain cock and open up the valve in the pressure pipe, when the cylinder is full the air cock is closed. The piston will be pushed out against the buffer and the ropes or chains by which the car was suspended will be loosened; when this is removed the car is ready to descend, the valve is shifted into position for going down. The elevator should not be run before the cylinder is thoroughly greased; this should be done twice a week as this will greatly prolong the wear of the packing.

Leaks that will occur in course of time may be stopped by loosening of the jamb nuts and by setting up of all the nuts of the studs equally until the leak stops, then the jamb nuts should be retightened.

How to Pack Vertical Cylinder Pistons.

On some vertical machines the piston is packed from the bottom, on others from the top; however, as far as the packing is concerned it is generally the same. The packing generally used consists of a leather cup, somewhat smaller than the diameter of the piston with several layers of $\frac{5}{8}$-inch duck packing on the outside, packing the piston from the bottom, the car must be run to top so that the piston strikes the bottom of the cylinder and the car must be secured to the overhead timber. The water must be drained all out of the cylinder by closing the valve on the pressure pipe, and by opening the air valve on top and the valves on the side and bottom drain pipes, and by placing the controlling valve in a position for going up. When the water has been all drained out of the cylinder the controlling valve is shifted into position for going down, this drains the water that had remained in the circulating pipe. When all the water is removed, the lower cylinder head is taken off; before removing the follower and piston head the exact position should be marked so that no trouble will be experienced to replace them; the piston shouid then be cleaned, especially the passages through which the water acts upon the leather cup. If the leather cup is found to be in good condition replace it and place 3 new rings of $\frac{5}{8}$-inch square duck packing on the outside, the packing, however, must not fill the space provided for the packing by a $\frac{1}{4}$-inch, as the water will swell the packing and cramp it so that water which acts on the leather cup can not force the packing out against the cylinder walls; if too thick, a few layers of the canvas should be stripped off. The piston head and follower may then be replaced, taking care that the piston rods do not get twisted. When the cylinder head is replaced the cylinder is ready to fill. The operating valve is placed into position for going down, the valves on the drain pipes closed and the valve in the pressure pipe gradually opened, so that cylinder fills gradually allowing all the air to escape through the air valve left open for that purpose. When the cylinder is filled the air valve is closed and the operating valve is placed on the center, and the car untied and after all adjustments have been made, the elevator is ready for use.

If the piston is packed from the top, the car is run to the bottom of the elevator shaft, the valve in pressure pipe is closed and the water is drained down level with the top of the piston. The top head is then removed and slipped up on the piston rods and fastened there out of the way. If the piston should be too far down in the cylinder to be accessible it may be raised by a small tackle to the hoisting cables a few feet above the car and drawn down far enough to bring the piston within easy reach.

The follower, after its exact position has been marked, is removed and repacking is the same as explained before, then the follower is replaced, the piston lowered if it was necessary to hoist it, the cylinder head replaced and the valve on the pressure pipe is then opened after making sure that the operating valve is on the center. As soon as the water appears at the air cock it is closed and the elevator is ready to run.

How to Pack Vertical Cylinder Valves.

To pack the valves in a vertical cylinder the car is run to the bottom and the water is drained all out of the cylinder, circulating pipe and valve after the manner as explained in packing the piston from the bottom of the cylinder. If a rack valve marks the position of the sheave and also the teeth of the rack pinion in relation with the rack, then remove the valve and place the new leather cups as the old ones were found, then replace all parts as found before. The operating valve is placed in position for going down and the system refilled.

The leather cups used for packing valves should be of even thickness and best quality and free from any defects; they also should be treated with a waterproof dressing before put in use. As the valve lining in which the operating valve moves is perforated, the cups should be of sufficient stiffness to withstand the pressure of the water. However leather cups are specially made for high and low pressure, a cup intended for high pressure will not expand when low pressure is used.

Lubrication for Hydraulic Elevators.

In hydraulic elevator plants where pumps and tanks are used, the most effectual method of lubricating the internal parts of the machinery is the introduction of the drip water of the exhaust from the pump and engines into the hydraulic system. This is best accomplished by piping from the foot all exhaust pipes to the discharge tank. The distilled water in connection with the cylinder oil forms an excellent lubricant.

The best lubricant for horizontal machines that are operated by hydrant pressure is a heavy grease applied with a piece of waste fastened to a pole—or mechanically, the latter is preferable, the lubrication being continuous, while in the former method greasing is often neglected, consequently the packing wears out quickly.

The main cables should be lubricated occasionally, as this adds greatly to their preservation. A compound consisting of cylinder oil, graphite and vegetable tar, heated and thoroughly mixed furnishes an excellent lubricant for this purpose; linseed oil applied to wire rope prevents rusting. The guides, if

made of steel, are best lubricated with cylinder oil; wood guides are best lubricated with grease; the guides should be cleaned at short intervals to prevent gumming. The best lubricant for overhead sheaves is a heavy grease in summer time, as the heat under the roof of the inclosure during this time will keep the grease soft and furnish good lubrication, in winter a heavy oil should be added as required.

General Directions.

The water that is used in hydraulic elevator plants should be filtered if possible, and should be changed every 3 months, and the system thoroughly washed and flushed. Should it become necessary to shut down for an indefinite time the car should be run to the bottom and the water from all parts should be drained off, to prevent freezing in cold weather and bursting of parts of the machinery. Horizontal cylinders should be greased inside with a heavy grease, and if vertical machines the rods should be greased; the cables should be oiled with raw linseed oil to prevent rusting.

If the bushings are worn on one side so that sheaves will bind they may be turned around and thus obtain a new bearing, but if they were turned before a new bushing is necessary.

The piston rods on a vertical machine should draw alike; if this is not the case it can be readily detected by trying to turn the rods by hand, sometimes by a groaning in the cylinder; this groaning, however, may be also caused by a leaky piston, in this case the car would settle after a stop is made. Settling of the car may also be caused by a leaky valve, or the air valve in piston may leak—not setting properly. If a kind of elastic or springy motion is noticed in the car when stopping there is air present in the cylinder. This may be removed, if there is not much air in the cylinder, by opening the air cock and making a few trips with the car, but if considerable air is present, the car should be run near the bottom, placing a block underneath for the car to rest upon, and throwing the operating valve into position for going down, and opening the air valve, allowing the air to escape. It may be necesary to repeat this several times. The stop buttons on hand cables should be adjusted so that the car will stop at either end before striking the cylinder head.

The governor and safety device should be tried occasionally to see that it works properly.

The whole system should be examined often—all bolts and nuts that are likely to get loose owing to shrinkage of timber or whatever cause. The cables should bear equal strain, controlling ropes should always have the proper tension, also the governor rope, which is likely to stretch with Gin-block resting

at the bottom, in such a case the rōpes must be shortened, otherwise they will not perform their proper functions. The wire twisting ropes should be examined frequently and when the wires (not strands) commence to crack, the ropes should be renewed. In no case should a hoisting cable be spliced. Machinery should always be kept clean.

REPAIR WORK

An engineer is often required to make repairs or alterations of machines, do experimental work, etc. This is especially true in factories where special machinery is employed to manufacture certain articles, and the operator is only able to run and feed his or her machine. Should the machine refuse to do the work the operator is helpless and the factory crippled to that extent until this machine is put in order again. In nine cases out of ten, the engineer is required to locate the trouble, and if any parts are broken, to make temporary repairs and keep the machine running until new parts can be had, which may take several days or even weeks, especially if the machine has been built at some distant machine shop. Considering these, only one of so many instances, it may be well understood that much depends on the capability of the engineer, who in case of trouble is the first person to be consulted and who is expected to overcome any obstacles as quickly as possible.

In some places a small shop, consisting of a turning lathe, drill-press, work bench with vise, set of taps and dies, etc., is at the command of the engineer, where he may amuse himself in his spare time in doing repair work; and a few points on handling a lathe may be useful to him.

The Lathe.

In order to do good work on the lathe, it must be in perfect order. The centers of the lathe must be in line and of proper shape, the spindle bearing must be kept just tight enough to keep from heating, the lead screw must be looked after, as much depends on this. This part is generally overlooked in cleaning the lathe, and if the lathe used for turning short spindles, studs or cutting threads, the lead screw will soon wear at that particular place, which will make it difficult to turn out good work, if not impossible. Cleanliness and good lubrication tends to prolong the life of a lathe as much as any other machine.

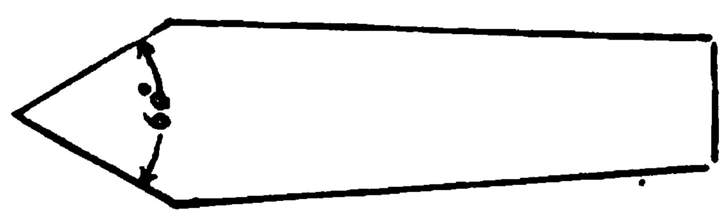


FIG. 1.

Lathe Centers.

In trueing off the centers they should be tapered to a point at an angle of 60 degrees, as shown in Figure 1. The life center, or

that center which revolves on the spindle, should be marked before removing it, so it may be put back in the same position, this insures always a true center. The centers should be hardened, as soft centers wear quickly and bend easily, and soon get out of true.

Testing the Centers.

The centers of a lathe are always liable to become out of true, and should always be tested before starting a piece of work where particular accuracy is required. One method of doing this is shown in Figure 2, it consists of an iron bar, equal in length to

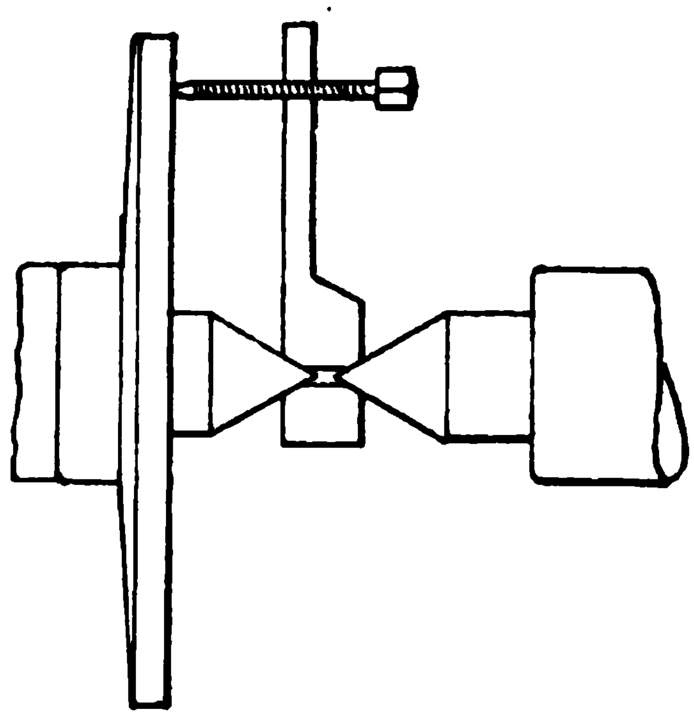


FIG. 2.

the radius of the face plate, a little larger in width at one end, in which a small hole is drilled through it and countersunk on both sides, not letting the two centers meet; this is put to the centers, as will be seen in the cut. The bar will stand a certain distance from the face plate; measure this distance and mark that place on the face plate, turn the face plate first 90° then 180° and 270° and if the distance is the same the centers are in line with the spindle. It will be readily understood, that on a face plate of large size this can be done more accurately than on a face plate of small diameter.

Work Centers.

In centering a piece of work, care should be taken that the taper of the center fits that of the lathe center, neither should the point of lathe bear against the metal. A small hole should be drilled first and then reamed out to suit the lathe center (see Figure 3) which shows the right way; Figure 4 shows the taper too large and the whole strain will be therefore near the point, causing the lathe center to bend or break easily; Figure 5 shows the work

centered less than 60°, causing a ring-shaped bearing and wears out the lathe center much faster.

For reaming out centers a square center is used a great deal.

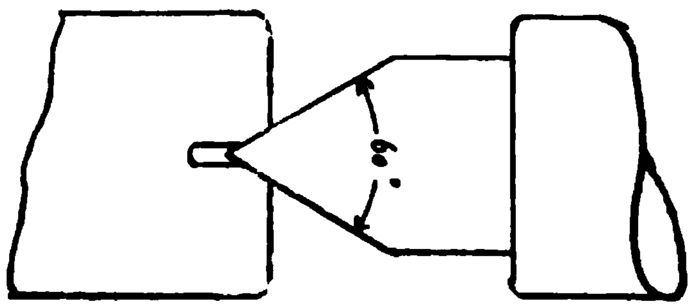


FIG. 3.

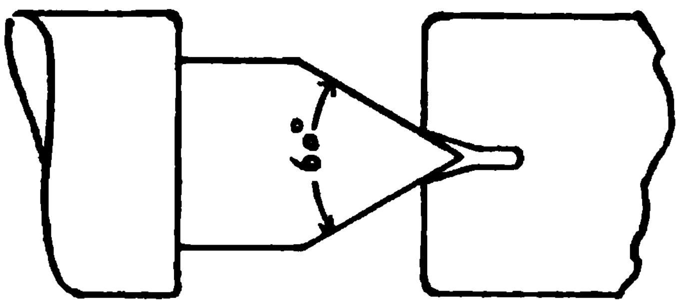


FIG. 4.

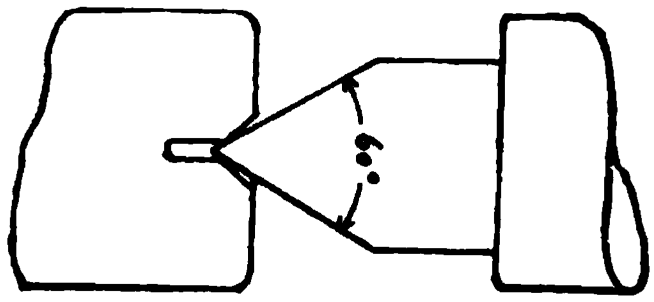


FIG. 5.

United States Standard Threads.

In Figures 6, 6a and 6b, the three forms of screw threads now in use in this country are shown. The United States Standard form has been adopted by the United States Government, the Master Mechanics' and Master Car Builders' Association; Locomotive Works, Machine Bolt Makers, and many manufacturing establishments throughout this country, and is recommended by the Franklin Institute in Philadelphia. The thread has an angle of 60° with flat top and bottom, equal to one-eighth of the pitch. The advantages of this form of thread over the V-shaped are that in the tap the edges of the thread are less liable to accidental injury, and will wear and retain their sizes and form longer, and in both the flat top and bottom give increased strength and a better appearance.

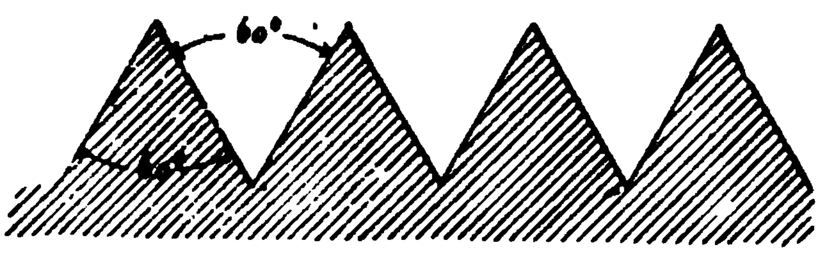


FIG. 6.

FIG. 6a.

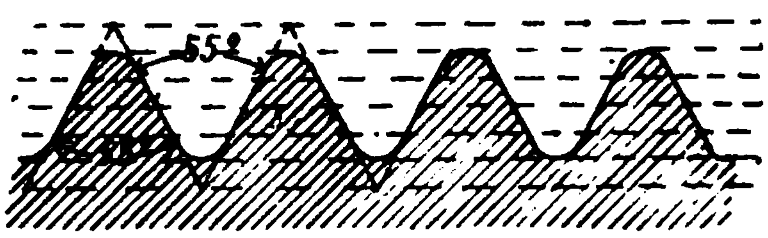


FIG. 6b.

The number of United States standard threads to the inch for bolts from ¼ inch up to 2 inches are given in Table I.

TABLE I.

STANDARD THREADS.

Diameter of Tap.	U. S. Standard. No. Threads to Inch.	V Thread. No. Threads to Inch.	Whitworth. No. Threads to Inch.
¼	20	20	20
5/16	18	18	18
⅜	16	16	16
7/16	14	14	14
½	13	12	12
⅝	11	11	11
¾	10	10	10
⅞	9	9	9
1	8	8	8
1⅛	7	7	7
1¼	7	7	7
1⅜	6	6	6
1½	6	6	6
1⅝	5½	5	5
1¾	5	5	5
1⅞	5	4½	4½
2	4½	4½	4½

To find the right size of drill for a certain tap, consult table I, first, for instance the size drill for one inch tap is wanted. In table I it shows eight threads to the inch. Now consult table II; the first column shows the size of tap, and by following up the line on one inch taps, it will be seen that the size of drill for V-shaped thread is 13/16 inch, for United States Standard 27/32 and the same size is needed for Whitworth's thread.

The following table shows the different sizes of drills that should be used when a full thread is to be tapped.

TABLE II.

TAP DRILLS FOR MACHINE AND HAND TAPS.

Diameter of Tap.	No. of Threads to Inch.			Drill for V Thread			Drill for U. S. Standard Thread.	Drill for Whitworth Thread.
1/4	16	18	20	5/32	5/32	11/64	3/16	3/16
9/32	16	18	20	3/16	13/64	13/64		
5/16	16	18		7/32	15/64		1/4	15/64
11/32	16	18		1/4	17/64			
3/8	14	16	18	1/4	9/32	9/32	9/32	9/32
13/32	14	16	18	19/64	21/64	21/64		
7/16	14	16		21/64	11/32		11/32	11/32
15/32	14	16		23/64	3/8			
1/2	12	13	14	3/8	25/64	25/64	13/32	3/8
17/32	12	13	14	13/32	27/64	27/64		
9/16	12	14.		7/16	29/64		7/16	
19/32	12	14		15/32	31/64			
5/8	10	11	12	15/32	1/2	1/2	1/2	1/2
21/32	10	11	12	1/2	17/32	17/32		
3/4	10	11	12	19/32	5/8	5/8	5/8	5/8
25/32	10	11	12	5/8	21/32	21/32		
7/8	9	10		45/64	23/32		23/32	23/32
29/32	9	10		47/64	3/4			
1	8			13/16			27/32	27/32
1 1/32	8			53/64				
1 1/8	7	8		29/32	15/16		15/16	15/16
1 5/32	7	8		15/16	31/32			
1 1/4	7			1 1/32			1 1/16	1 1/16
1 9/32	7			1 1/16				
1 3/8	6			1 1/8			1 5/32	1 5/32
1 13/32	6			1 5/32				
1 1/2	6			1 15/64			1 9/32	1 9/32
1 17/32	6			1 9/32				
1 5/8	5	5 1/2		1 9/32	1 15/16		1 3/8	1 23/64
1 21/32	5	5 1/2		1 5/16	1 11/32			
1 3/4	5			1 13/32			1 1/2	1 1/2
1 25/32	5			1 7/16				
1 7/8	4 1/2	5		1 17/32	1 17/32		1 5/8	1 37/64
1 29/32	4 1/2	5		1 9/16	1 9/16			
2	4 1/2			1 21/32			1 23/32	1 45/64

Gearing a Lathe for Screw Cutting.

Simple Gears.

The gearing of screw cutting lathes is divided into two kinds; the simple gearing and the compound gearing.

Where simple gearing is employed, only two gears need to be changed for cutting any number of threads within the range of the gears. These are, the gear on the spindle and the gear on the lead screw. Lathes which have a fixed gear on the spindle, which cannot be changed, are usually geared compound.

In lathes whose spindle gear is changeable, it matters not whether the gear to be changed is on the shaft which carries the pulley (on such lathes the gear is usually outside), or whether the gear on the shaft meshes into another, or counter gear, carrying the spindle on which the different gears are placed. Such an arrangement of the driving gear is sometimes called "inside," because the first gear is usually on the inside and the spindle on the outside. In nearly all the lathes of this kind the gears are of the same diameter, so that the result is the same as it would be were there only one. However, it may be found that the driver on the spindle has only one-half the number of teeth which the second one has; in this case the number of teeth of the wheel that is to be placed on the spindle must be doubled.

There are many useful rules and methods for finding the gearing required for screw-cutting. The one here given may not be the best, but it is applicable to all cases and sets of gears and is very simple. The first thing to do is to find what gears are at hand, so that it will not be necessary to handle them every time a calculation is made to determine whether one has the one corresponding to his figures. Then it is necessary to know the number of threads per inch on the feed or lead screw; when a screw is to be cut, ascertain the number of threads per inch which the work requires. With simple gearing, the two gears necessary are found by multiplying the number of threads (per inch) on the lead screw, and the number of threads (per inch) to be cut by the same number. If one has an absolutely complete set of gears (which is seldom the case), it will make no difference what that same is, whether 2, 3, 4, 5, 6, 7, or any other number. Any number will give the proper ratio and will answer as long as it gives gears that are on hand; therefore, a number that will give gears that are on hand must be selected. This is done only by trial, but if one knows the gears he has in stock, the calculation can be easily made mentally.

Rule.

Multiply by a number that will give two gears which you have in stock as follows: To find the gear for the spindle, multi-

ply it (the number selected) by the number of threads per inch on the lead screw. To find the gear for the lead screw multiply it by the number of threads (per inch) to be cut.

Example.

It may be well to state that no gears having less than twenty teeth are usually furnished with a lathe. The question may also arise in the reader's mind, why the stud or intermediate gears are not taken into consideration.

With compound gearing they play an important part in the calculation, but with simple gearing this need not be thought of, for whatever the number or diameter, any number of tooth movement on the spindle gear will give the same on the lead screw gear. For instance, we wish to cut twelve threads to the inch on a piece of work; suppose that there are five threads per inch on the lead screw; many for the first trial square the threads on the lead screw, or multiply such number by itself. We will begin as follows: Number of threads on lead screw=5 and 5×5=25; according to the rule, this gives the number of teeth of the gear on the spindle. If we have a gear with 25 teeth, we may proceed to multiply the number selected (5) by the number of threads per inch we wish to cut, to find the number of teeth for the gear on the lead screw.

Number of threads to be cut=12 and 12×5=60. If we have a gear with 60 teeth we may proceed with the job of screw cutting. If we have not, but have a gear of twenty teeth, 5 (the number of teeth per inch of the lead screw) is contained in 20=4 times, we also have a 48 gear, 48 divided by the number of threads we wish to cut, which is 12, we have 4 again, therefore 4 is the number to be selected.

Compound or Pinion Gears.

A compound gear is a cone gear with two steps, the number of teeth in smaller, being to number of teeth in the larger, as 2 to 4 or as 2 to 8. In the remarks on simple gearing, it was stated, that it does not make any difference what stud or intermediate gears are used; this does not apply to compound gear, but only to simple gear. Intermediate gear wheels may be used with compound gears, however, without affecting the result; sometimes it is necessary to use them to transmit the motion to or from a compound.

Rule.

Select the compound gear to be used, say one 2 to 4. Find the ratio between the number of threads per inch on the lead screw and number of threads per inch to be cut, by dividing the

latter by the former; then multiply the number of teeth on the spindle gear by the number of teeth on the lesser step (or the driver) of the compound gear. Multiply this product by the ratio above referred to and divide this product by the number of teeth on the greater step (or the driven) of the compound gear. The result will be the gear for the lead screw; if it is not on hand, try another compound gear.

Example.

Number of threads on lead screw, 5. Number of threads to be cut, 32. Number of teeth in spindle gear, 20. Number of teeth in compound, 20 and 40. What is the gear for the lead screw?

Solution.—Ratio of thread on lead screw to threads to be cut equal $32 \div 5 = 6.4$.

Number of teeth on spindle gear 20×20 (number of teeth on lesser of compound)$=400$. $6.4 \times 400 = 2560$. Number of teeth on greater compound, 40. $2560 \div 40 = 64$, number of teeth on gear to go on the lead screw.

Screw or V-Shaped Threads.

When cutting V-shaped threads, set your tool at right angle with the lathe centers, and look at thread carefully on both sides, and see that the threads do not lean like fish-scales. Always grind your tool to a gauge.

Square Threads.

When cutting square threads it is always necessaary to get the depth with a tool somewhat thinner than one-half the pitch of the thread. After doing this, dress another tool exactly one-half the pitch of the thread and use it to finish with, cutting a slight chip on each side of the groove; then polish with a pine stick and emery. Square threads for strength should be one-half the depth of their pitch, while square threads for wear should be cut three-fourths the depth of their pitch.

Mongrel Threads.

Mongrel, or half V and half square threads, are usually made for great wear, and should be cut the full depth of the pitch, or even more. They are sometimes cut one and one-half the depth of their pitch; the point and the bottom of the grooves should be in width one-quarter of their pitch.

Double Threads.

The face plate on most all lathes has at least four slots in it which carry the dog, so after you have cut one thread, change the dog to slot directly opposite on the face plate.

Left-Hand Thread.

Proceed with the work the same as for right-hand thread, and change the shifter at the end of the left, so as to move the tool from left to right.

Lathe Tools.

In Figure 7 is shown a set of lathe tools, such as is required to do ordinary work.

No. 1. Left-hand side tool.
No. 2. Right-hand side tool.
No. 3. Right-hand bent tool.
No. 4. Right-hand diamond point.
No. 5. Left-hand diam nd point.
No. 6. Round-nose tool.
No. 7. Cutting-off tool.
No. 8. Threading tool.
No. 9. Bent threading tool.
No. 10. Roughing tool.
No. 11. Boring tool.
No. 12. Inside threading tool.

Table III. Speed of drills as applied to steel, iron or brass in its normal condition.

TABLE III.

Diameter of Drill.	Revolutions per Minute.		
	Steel.	Iron.	Brass.
1/16	890	1220	1550
1/8	445	630	775
3/16	291	405	525
1/4	223	305	395
5/16	178	245	315
3/8	148	205	260
7/16	122	175	225
1/2	111	150	195
9/16	98	135	175
5/8	89	125	155
11/16	81	110	140
3/4	74	100	125
13/16	69	95	115
7/8	67	85	110
15/16	59	80	105
1	55	75	100
1 1/16	52	70	95
1 1/8	49	68	90
1 3/16	46	65	80
1 1/4	44	60	75
1 5/16	42	58	70
1 3/8	40	56	68
1 7/16	38	54	65
1 1/2	37	52	63
1 9/16	35	50	60
1 5/8	34	48	58
1 11/16	33	46	55
1 3/4	32	44	53
1 13/16	31	42	50
1 7/8	30	40	49
1 15/16	29	39	46
2	28	38	45
2 1/16	28	37	44
2 1/8	27	35	43
2 3/16	27	34	42
2 1/4	26	33	41
2 5/16	25	33	40
2 3/8	25	32	39
2 7/16	24	31	38
2 1/2	23	30	37
2 9/16	22	30	36
2 5/8	22	29	35
2 3/4	21	28	34
2 7/8	20	27	33
3	19	26	32

STRENGTH OF WROUGHT IRON BOLTS.

Diameter of Bolt in Inches.	Safe Load in Pounds.	Diameter of Bolt in Inches.	Safe Load in Pounds.
1/2	1000	1 1/4	8050
5/8	1800	1 3/8	10000
3/4	2750	1 1/2	11800
7/8	3800	1 3/4	15750
1	5000	2	20800
1 1/8	6250		

WORKSHOP RECIPES.

To Temper Steel Very Hard.—Water, 4 parts; flour, 1 part; salt, 2 parts, mixed to a paste. Heat the steel until a coating adheres when dipped into the mixture; then heat to a cherry red and cool in cold soft water. The steel will come out white and very hard.

To Temper Steel on One Edge Only.—Dip the edge to be tempered into hot lead until the proper color; then temper in ordinary fashion.

To Drill Hardened Steel.—Cover your steel with melted beeswax; when coated and cold, make a hole in the wax with a fine pointed needle or other article the size of holes you require, put a drop of strong nitric acid upon it; after an hour rinse of and apply again; it will gradually eat through.

A mixture of 1 ounce of sulphate of copper, ¼ ounce of alum, ½ teaspoonful of powdered salt, 1 gill vinegar and 20 drops of nitric acid will make a hole in steel that is too hard to cut or file easily.

A small hole drilled at the end of a crack in sheet steel will stop it from growing longer.

Annealing Steel.—For small pieces of steel, take a piece of gas-pipe two or three inches in diameter, and put the pieces in it, first heating one end of the pipe, and drawing it together, leaving the other end open to look into. When the pieces are of a cherry red, cover the fire with sawdust, use a charcoal fire, and leave the steel in over night.

In Turning Steel or Other Hard Metal.—Use a drip composed of petroleum two parts, and turpentine one part. This will insure easy cutting and perfect tools when otherwise the work would stop, owing to the breakage of tools from the severe strain.

Tempering Recipes.—Rosin, 2 lbs.; tallow, 2 lbs.; pitch, 1 lb. Melt together and dip the hot steel in it.

Salt, ½ cupful; saltpetre, ½ oz.; alum, pulverized, 1 teaspoonful; soft water, 9 gals. Never heat above a cherry red nor draw any temper.

By melting together 1 gal. spermacetti oil, 2 lbs. tallow and ¼ lb. wax, a mixture is obtained very convenient for tempering any kind of steel article of small size. Adding 1 lb. rosin makes it suitable for larger articles.

To Harden Gravers.—Heat in charcoal dust (not too hot), and plunge into a box of wet, yellow soap. This renders the end of the graver very hard and very tough.—Machinery.

Strong sal soda water or soapy water is much better than clean water to use where water cuts are being taken, either on the

lathe or planer. In cutting brass, sweet milk is recommended as being better than either the foregoing.

Pipe Fitting.

Pipe fitting, whether by installing a new steam plant, or by making alterations and additions, should be done as simply as possible; this adds greatly to the appearance and neatness of the plant. All sharp bends should be avoided wherever possible, this does away with unnecessary friction, allows for expansion in long lines of pipes; this is too often overlooked and causes no end of trouble, by springing leaks or even bursting joints. The pipe line (if horizontal) should have fall enough to drain itself in the direction the steam flows; if a reduction is made, it should be provided with a drain cock at that point.

Wherever a steam pipe passes through a floor or wooden partition or other combustible material, it must be properly insulated to guard against fire, and should be well secured to ceilings, walls, etc., by suitable hangers or brackets, as the situation may require.

All pipe lines starting from the boiler must be provided with valve as close as possible to the latter, a union near at hand to disconnect in case of valve renewal or for other reasons. The same is true at the termination of pipe line, it often happens that the union is placed several lengths away from the apparatus where the stream is used; this will be found very inconvenient, if the apparatus must be disconnected in a hurry, which will very likely happen some day.

All pipes should be covered; this prevents condensation to a great extent and saves fuel. Some forethought is also necessary; steam may be wanted between lengths; a few Ts saves breaking joints and tearing off covering besides the time required to do it, and pipe may also be of little larger size than for present wants.

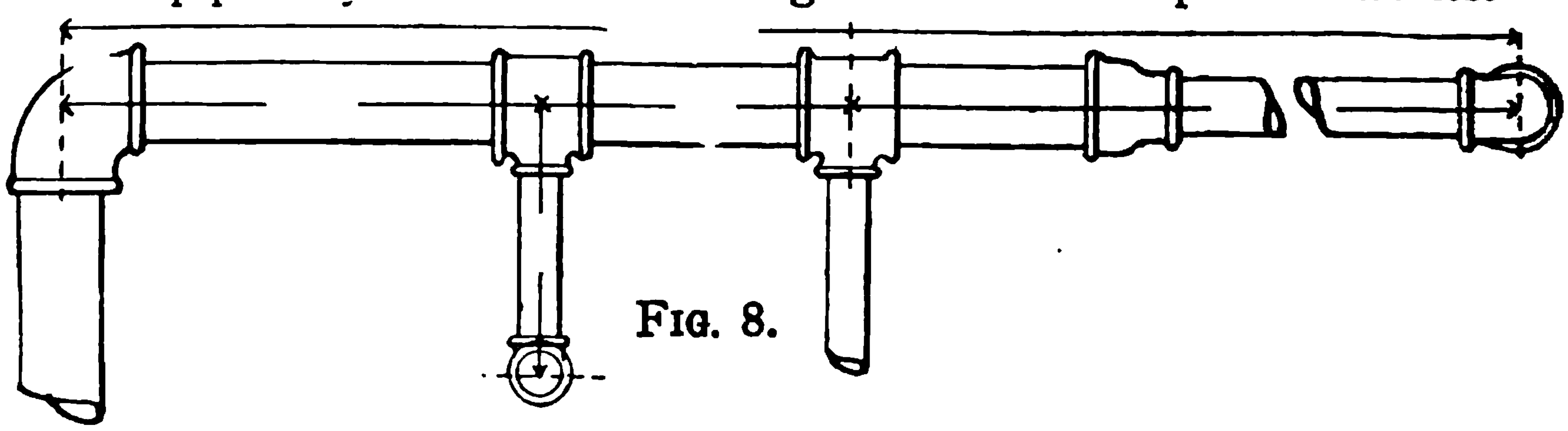


FIG. 8.

Taking Measurements of Pipes.

In taking measurements it should be taken from the centers of the fittings as shown in Figure 8. A diagram should be made and the centers marked thereon and also the whole length should be given. In table IV the standard dimension of wrought iron welded steam, gas and water pipe is given and may be found to some advantage in ordering pipes.

TABLE IV.

WROUGHT IRON WELDED STEAM, GAS AND WATER PIPE—Table of Standard Dimensions.

Diameter.			Thickness.	Circumference.		Transverse Areas.			Length of Pipe per Square Foot of		Length of Pipe containing One Cubic Foot.	Weight per Foot of Length	No. of Threads per Inch of Screw.	Number of Galls. per Foot of Length.	Weight Water per Foot of Length
Nominal Internal.	Actual External.	Actual Internal.		External.	Internal.	External.	Internal.	Metal.	External Surface.	Internal Surface.					
Inches	Inches.	Inches.	Inches.	Inches.	Inches.	Sq. Inch.	Sq. Inch.	Sq. Inch.	Feet.	Feet.	Feet.	Lbs.		Gallons.	Lbs.
1/8	.405	.27	.068	1.272	.848	.129	.0573	.0717	9.44	14.15	2513.	.241	27	.0006	.005
1/4	.54	.364	.088	1.696	1.144	.229	.1041	.1249	7.075	10.49	1383.3	.42	18	.0026	.021
3/8	.675	.494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.73	751.2	.559	18	.0057	.047
1/2	.84	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.13	472.4	.837	14	.0102	.085
3/4	1.05	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270.	1.115	14	.0230	.190
1	1.315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.9	1.668	11½	.0408	.349
1¼	1.66	1.38	.14	5.215	4.335	2.164	1.496	.668	2.301	2.768	96.25	2.244	11½	.0638	.527
1½	1.9	1.611	.145	5.969	5.061	2.835	2.038	.797	2.01	2.371	70.66	2.678	11½	.0918	.760
2	2.375	2.067	.154	7.461	6.494	4.43	3.356	1.074	1.608	1.848	42.91	3.609	11½	.1632	1.356
2½	2.875	2.468	.204	9.032	7.753	6.492	4.784	1.708	1.328	1.547	30.1	5.739	8	.2550	2.116
3	3.5	3.067	.217	10.996	9.636	9.621	7.388	2.243	1.091	1.245	19.5	7.536	8	.3678	3.049
3½	4.	3.548	.226	12.566	11.146	12.566	9.887	2.679	.955	1.077	14.57	9.001	8	.4998	4.155
4	4.5	4.026	.237	14.137	12.648	15.904	12.73	3.174	.849	.949	11.31	10.665	8	.6528	5.405
4½	5.	4.508	.246	15.708	14.162	19.635	15.961	3.674	.764	.848	9.02	12.34	8	.8263	6.851
5	5.563	5.045	.259	17.477	15.849	24.306	19.99	4.316	.687	.757	7.2	14.502	8	1.020	8.500
6	6.625	6.065	.28	20.813	19.054	34.472	28.888	5.584	.577	.63	4.98	18.762	8	1.469	12.312
7	7.625	7.023	.301	23.955	22.063	45.664	38.738	6.926	.501	.544	3.72	23.271	8	1.999	16.662
8	8.625	7.982	.322	27.096	25.076	58.426	50.04	8.386	.433	.478	2.88	28.177	8	2.611	21.750
9	9.625	8.937	.344	30.238	28.076	72.76	62.73	10.03	.397	.427	2.29	33.701	8	3.300	27.500
10	10.75	10.019	.366	33.772	31.477	90.763	78.839	11.924	.355	.382	1.82	40.065	8	4.081	34.000
11	12.	11.25	.375	37.699	35.343	113.098	99.402	13.696	.318	.339	1.456	45.95	8	....	....
12	12.75	12.	.375	40.055	37.7	127.677	113.098	14.579	.299	.319	1.27	48.985	8	....	....
13	14.	13.25	.375	43.982	41.626	153.938	137.88	16.051	.273	.288	1.04	53.922	8	....	....
14	15.	14.25	.375	47.124	44.768	176.715	159.485	17.23	.255	.268	.903	57.893	8	....	....
15	16.	15.25	.375	50.265	47.909	201.062	182.655	18.407	.239	.250	.788	61.77	8	....	....
....	18.	17.25	.375	56.549	54.192	254.47	233.706	20.764	.212	.221	.616	69.66	....	....	....
....	20.	19.25	.375	62.832	60.476	314.16	291.04	23.12	.191	.198	.495	77.57	....	....	....
....	22.	21.25	.375	69.115	66.759	380.134	354.657	25.477	.174	.179	.406	85.47	....	....	....
....	24.	23.25	.375	75.398	73.042	452.39	424.558	27.832	.159	.164	.339	93.37	....	....	....

TABLE V.

WROUGHT IRON WELDED EXTRA STRONG PIPE.—Table of Standard Dimensions.

Diameter. Nominal Internal.	Diameter. Actual External	Diameter. Actual Internal.	Thickness.	Nearest Wire Gauge.	Circumference. External.	Circumference. Internal.	Transverse Areas. External.	Transverse Areas. Internal.	Transverse Areas. Metal.	Length of Pipe per Square Foot of External Surface.	Length of Pipe per Square Foot of Internal Surface.	Nominal Weight per Foot.
Inches.	Inches.	Inches.	Inches.	No.	Inches.	Inches.	Sq. Inches.	Sq. Inches.	Sq. Inches.	Feet.	Feet.	Pounds.
1/8	.405	.205	.1	12½	1.272	.644	.129	.033	.086	9.433	18.632	.29
1/4	.54	.294	.23	11	1.696	.924	.229	.068	.161	7.075	12.986	.54
3/8	.675	.421	.127	10½	2.121	1.323	.358	.139	.219	5.657	9.07	.74
1/2	.84	.542	.149	9	2.639	1.703	.554	.231	.323	4.547	7.046	1.09
3/4	1.05	.736	.157	8½	3.299	2.312	.866	.452	.414	3.637	5.109	1.39
1	1.315	.951	.182	7	4.131	2.988	1.358	.71	.648	2.904	4.016	2.17
1¼	1.66	1.272	.194	6½	5.215	3.996	2.164	1.271	.893	2.301	3.008	3.
1½	1.9	1.494	.203	6	5.969	4.694	2.835	1.753	1.082	2.01	2.556	3.63
2	2.375	1.933	.221	5	7.461	6.073	4.43	2.935	1.495	1.608	1.975	5.02
2½	2.875	2.315	.28	2	9.032	7.273	6.492	4.209	2.283	1.328	1.649	7.67
3	3.5	2.892	.304	1	10.996	9.085	9.621	6.569	3.052	1.091	1.328	10.25
3½	4.	3.358	.321	0	12.566	10.549	12.566	8.856	3.71	.955	1.137	12.47
4	4.5	3.818	.341	0	14.137	11.995	15.904	11.449	4.455	.849	1.	14.97
5	5.563	4.813	.375	00	17.477	15.120	24.306	18.193	6.12	.687	.793	20.54
6	6.625	5.75	.437	000	20.818	18.064	34.472	25.967	8.505	.577	.664	28.58

TABLE VI.

DOUBLE EXTRA STRONG PIPE.

Nominal Internal.	Actual External	Actual Internal.	Thickness.	Nearest Wire Gauge.	Circumference External.	Circumference Internal.	Area External.	Area Internal.	Area Metal.	Length per Sq. Ft. External Surface.	Length per Sq. Ft. Internal Surface.	Nominal Weight per Foot.
1/2	.84	.244	.298	1	2.639	.766	.554	.047	.507	4.547	15.667	1.7
3/4	1.05	.422	.314	1	3.299	1.326	.866	.139	.727	3.637	9.049	2.44
1	1.315	.587	.364	00	4.131	1.844	1.358	.271	1.087	2.904	6.508	3.65
1¼	1.66	.885	.388	00	5.215	2.78	2.164	.615	1.549	2.304	4.317	5.2
1½	1.9	1.088	.406	000	5.969	3.418	2.835	.93	1.905	2.01	3.511	6.4
2	2.375	1.491	.442	0000	7.461	4.684	4.43	1.744	2.686	1.608	2.561	9.02
2½	2.875	1.755	.560	9/16—	9.032	5.513	6.492	2.419	4.073	1.328	2.176	13.68
3	3.5	2.284	.608	5/8—	10.996	7.175	9.621	4.097	5.524	1.091	1.672	18.56
3½	4.	2.716	.642	5/8+	12.566	8.533	12.566	5.794	6.772	.955	1.406	22.75
4	4.5	3.136	.682	11/16—	14.137	9.852	15.904	7.724	8.18	.849	1.217	27.48
5	5.563	4.063	.75	3/4	17.477	12.764	24.306	12.965	11.34	.687	.940	38.12
6	6.625	4.875	.875	7/8	20.813	15.315	34.472	18.068	15.890	.577	.784	53.11

TABLE VII.

CAPACITIES OF TANKS IN BARRELS OF 31½ GALLONS.

Depth in Feet.	DIAMETER IN FEET.															
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
5	23.3	33.6	45.7	59.7	75.5	93.2	112.8	134.3	157.6	182.8	209.8	238.7	269.5	302.1	336.6	378.0
6	28.0	40.3	54.8	71.7	90.6	111.0	135.4	161.1	189.1	219.3	251.8	286.5	323.4	362.6	404.0	447.6
7	32.7	47.0	64.0	83.6	105.7	130.6	158.0	188.0	220.6	255.9	293.7	334.2	377.3	423.0	471.3	522.2
8	37.3	53.7	73.1	95.5	120.9	149.1	180.5	214.8	252.1	292.4	335.7	382.0	431.2	484.4	538.6	596.8
9	42.0	60.4	82.2	107.4	136.0	167.9	203.1	241.7	283.7	329.0	377.7	429.7	485.1	543.8	605.9	671.4
10	46.7	67.1	91.4	119.4	151.1	186.5	225.7	268.4	315.2	365.5	419.6	477.4	539.0	604.3	673.3	746.0
11	51.3	73.9	100.5	131.3	166.2	205.1	248.2	295.4	346.7	402.1	461.6	525.2	592.9	667.7	740.6	820.6
12	56.0	80.6	109.7	143.2	181.3	223.8	270.8	322.3	378.2	438.6	503.5	572.0	646.8	725.1	807.9	895.2
13	60.7	87.3	118.8	155.2	196.4	242.4	293.4	349.1	409.7	475.2	545.5	620.7	700.7	785.5	875.2	969.8
14	65.3	94.0	127.9	167.1	211.5	261.1	315.9	376.0	441.3	511.0	587.5	668.2	754.6	846.0	942.6	1044.4
15	70.0	100.7	137.1	179.0	226.6	279.8	338.5	402.8	472.8	548.3	629.4	716.2	808.5	906.4	1009.9	1119.0
16	74.7	107.4	146.2	191.0	241.7	298.4	361.1	429.7	504.3	584.9	671.4	773.9	862.4	966.8	1077.2	1193.6
17	79.3	114.1	155.4	202.9	556.8	317.0	383.6	456.6	535.8	621.4	713.4	811.6	916.3	1027.2	1144.6	1268.2
18	84.0	120.9	164.5	214.8	272.0	335.7	406.2	483.4	567.3	658.0	755.3	859.4	970.2	1087.7	1211.9	1342.8
19	88.7	127.6	173.6	226.8	287.0	354.3	428.8	510.3	598.0	694.5	797.3	907.1	1024.1	1148.1	1279.2	1474.4
20	93.3	134.3	182.8	238.7	302.1	373.0	451.3	537.1	634.4	731.1	839.3	954.9	1078.0	1208.5	1346.5	1492.0

TO FIND CAPACITY OF ANY SIZE TANK.

Diameter in feet × diameter in feet × depth in feet × 5.878 = Gallons.
Diameter in feet × diameter in feet × depth in feet × .1865 = Barrels of 31½ Gallons.
Cylindrical Inches × .0034 = Gallons.

TABLE IX.

TABLE OF BRANCH PIPES OF EQUAL AREA TO MAIN PIPE.

Main Pipe. Ins.	½"	⅜"	½"	¾"	1"	1¼"	1½"	2"	2½"	3"	4"	5"	6"	7"	8"	10"	12"
1	16	7	4	......	......	......	......	......	......	......	......	......	......	......	......	......	......
1¼	25	11	6	3	......	......	......	......	......	......	......	......	......	......	......	......	......
1½	36	16	9	4	2	......	......	......	......	......	......	......	......	......	......	......	......
2	64	28	16	7	4	2½	......	......	......	......	......	......	......	......	......	......	......
2½	100	44	25	11	6	4	3	......	......	......	......	......	......	......	......	......	......
3	144	64	35	16	9	6	4	2	......	......	......	......	......	......	......	......	......
4	256	114	64	28	16	10	7	4	2½	......	......	......	......	......	......	......	......
5	400	177	100	44	24	16	12	6	4	3	......	......	......	......	......	......	......
6	576	256	144	64	36	24	16	9	6	4	2	......	......	......	......	......	......
7	784	348	196	87	49	31	21	12	8	5	3	2	......	......	......	......	......
8	1,024	456	256	112	64	40	28	16	10	7	4	2½	2	......	......	......	......
10	1,600	711	400	177	100	64	44	25	16	11	6	4	3	2	......	......	......
12	2,304	1,024	576	256	144	96	64	36	24	16	8	6	4	3	2	......	......
16	4,096	1,824	1,024	448	256	160	112	64	40	28	16	10	7	5	4	2½	......
24	9,216	4,096	2,304	1,024	576	384	256	144	96	64	32	24	16	12	9	6	4
30	14,400	6,400	3,600	1,600	900	576	400	222	144	100	55	36	25	18	14	9	6
36	20,761	9,216	5,190	2,304	1,297	829	576	324	207	144	81	52	36	26	20	13	9

The above table will be found useful in finding at one view the number of branch pipes that will be equal to the main pipe for steam, water or gas. All pipes are measured by the internal diameter in inches.

TABLE VIII.

TABLE GIVING THE PRESSURE IN POUNDS DUE TO ANY CERTAIN HEIGHT OF A COLUMN OF WATER.

Head in Feet.	Pressure in Pounds per Square inch.	Head in Feet.	Pressure in Pounds per Square inch	Head in Feet.	Pressure in Pounds per Square inch.	Head in Feet.	Pressure in Pounds per Square inch.
1	.43	20	8.66	55	23.83	90	38.90
2	.88	25	10.83	60	25.90	95	41.07
3	1.30	30	12.	65	28.06	100	43.33
4	1.74	35	15.16	70	30.55	125	54.17
5	2.16	40	17.33	75	32.72	150	65.
10	4.33	45	19.50	80	34.66	175	76.05
15	6.50	50	21.66	85	36.83	200	86.67

Expansion and Contraction.

Cast iron will expand 1/162,000 of its length for each degree Fahr. it is subjected to within ordinary limits while in its solid state.

Wrought iron expands 1/15,000 of its length for each degree Fahr. To find the expansion of a line of pipe, multiply its length in inches by the number of degrees of temperature applied and divide the product by 150,000.

Example:—A pipe line is 100 feet long and the temperature 338°. Expansion $= \dfrac{100' \times 12'' \times 338^\circ}{150{,}000} = 2.7$ inches.

Pay special attention to pipe lines of considerable length. There is scarcely anything that can withstand this expansion, all branch pipes must be so connected that they may turn in their joints, which can be accomplished by making swing joints.

Rule for Calculating Speed and Size of Pulleys.

To find the size of the driving pulley, multiply the diameter of the driven by the number of revolutions it shall make and divide the product by the number of revolutions of the driver.

To find the diameter of the driven, multiply the diameter of the driver by its number of revolutions and divide by the number of revolutions the driven pulley makes; the result will be the diameter of the driven pulley.

To find the number of revolutions of the driven pulley, multiply the diameter of the driver by the number of its revolutions and divide the product by the diameter of the driven.

Horse-Power of Shafting.

For prime movers or head shafts, the main bearings are assumed to be 12 inches or less from receiving or driving pulleys.

Explanation:—D, diameter. R, revolutions per minute.

Formula for prime mover, $H.\text{-}P. = \frac{D^3 \times R}{100}$.

Example:—A shaft of 4″ diameter and 160 revolutions per minute would be $\frac{4 \times 4 \times 4 \times 160}{100} = 102.4$ H.-P.

For second mover divide by 80 $\frac{4 \times 4 \times 4 \times 16}{80} = 128$ H. P.

Horse-Power of Belting.

To find the size of belt when speed in feet per minute and horse-power wanted are given. For single belt, divide the speed of belt by 800. The horse-power wanted divided by this quotient will give the width of the belt required. For double belt divide the speed by 560 and the horse-power wanted divided by this quotient will give width of belt. This applies to belting having a contact of 180° or, in other words, for pulleys of the same size. When the pulleys differ in size, the smaller one is only considered in the calculation; such pulleys have no contact of 180°, and the first thing to do is to ascertain the number of degrees in contact and the horse-power may be found by consulting the following table as given by R. J. Abernathy, using 5 divisions as follows:

For 180° useful effect	1.00
For 157½° useful effect	.92
For 135° useful effect	.84
For 112½° useful effect	.76
For 90° useful effect	.64

To ascertain the power a belt will transmit under the 180 degree basis: Divide the speed of belt in feet per minute by 800, multiply by the width in inches and by 1.00. For the second named condition we only obtain 92 per cent of the above result and so on. As an example: What will be the transmitting power of a belt traveling 2,000 feet per minute, by each of the above rules, the belt to be 14 inches wide?

First. $\dfrac{2{,}000 \times 14 \times 1.00}{800} = 35.$

Second. $\dfrac{2{,}000 \times 14 \times .92.}{800} = 32.2.$

Third. $\dfrac{2{,}000 \times 14 \times .84}{800} = 29.4.$

Fourth. $\dfrac{2{,}000 \times 14 \times .76}{800} = 26.6.$

Fifth. $\dfrac{2{,}000 \times 14 \times .64}{800} = 22.4.$

If the degrees of contact come between the divisions named above, calculate from the first rule below.

To find the width of a belt, the speed and horse-power being given, divide the speed of belt in feet per minute by 800 and the horse-power wanted divided by this product and by 1.00 for the first named condition, will give the width of the belt required.

If speed of belt is 2,000 as stated above and the horse-power wanted is 35.

Speed. H.-P.

$\dfrac{2{,}000}{800} = 2.5$ and $\dfrac{35}{2.5} = 14''$ and $\dfrac{14}{1.00} = 14.$

$\dfrac{2{,}000}{800} = 2.5$ and $\dfrac{35}{2.5} = 14''$ and $\dfrac{14}{0.92} = 15.23.$

$\dfrac{2{,}000}{800} = 2.5$ and $\dfrac{35}{2.5} = 14''$ and $\dfrac{14}{0.84} = 16.66.$

$\dfrac{2{,}000}{800} = 2.5$ and $\dfrac{35}{2.5} = 14''$ and $\dfrac{14}{0.76} = 18.42.$

$\dfrac{2{,}000}{800} = 2.5$ and $\dfrac{35}{2.5} = 14''$ and $\dfrac{14}{0.64} = 21.87.$

From the above we see that width of belt increases as the degrees of contact decreases.

To Find Length of Belt.

Measure the distance between centers of the shaft, add the diameter of the two pulleys together, divide the result by two and multiply the quotient by 3.25, add the product to twice the distance between centers of shaft.

In punching a belt an oval punch should be used, the longer diameter of the punch being parallel with the length of belt so as to cut off as little leather as possible. There should be two rows of holes at each end, placed zig zag. The holes must not be unnecessarily large, just large enough to admit the lacing.

In 2 inch belt, punch 3 holes at each end.
In $2\frac{1}{2}$ inch belt, punch 4 holes at each end.
In 3 inch belt, punch 5 holes at each end.
In 4 inch belt, punch 7 holes at each end.
In 5 inch belt, punch 9 holes at each end.
In 6 inch belt, punch 11 holes at each end.
In 8 inch belt, punch 15 holes at each end.
In 10 inch belt, punch 19 holes at each end.
In 12 inch belt, punch 23 holes at each end.

The center of the hole should not come nearer to the side of the belt than $\frac{5}{8}$ of an inch, and not nearer to the end than $\frac{7}{8}$ of an inch. The second row should be at least $1\frac{3}{4}$ inches from the end; in wide belts this distance should be even a little greater.

Cut your belt exactly square at ends and begin to lace at center and lace both sides with equal tightness; do not cross lacing on contact side.

How to Put Up a Line Shaft.

If a line shaft is to be placed in a building, its position is generally parallel or in right angle to one of the walls, this depends entirely on the shape of the building, the machinery employed, etc.; this must be ascertained first. When the location is ascertained, we stretch a line in exact position of the shaft to be hung; we next ascertain the position of the first hanger, and dropping a plumb line from ceiling just touching the shaft line, make a mark on the ceiling, measure off the distance between hangers and follow on up the line. When all centers are marked, draw lines in right angle with the shaft line through these somewhat longer than the base of the hangers. Next cut a piece of board exactly as long as the base of hanger and draw a line lengthwise through the center, stand hanger on floor and adjust the bearing so that it lays in right angle with the base, place the strip of board alongside the base and square down center of bearing and mark on the board, then square over the center of the slotted holes and mark on the board also. This gives you the location of the bolt holes. If all hangers are alike one of these patterns will suffice, otherwise a pattern must be made for each

hanger of different construction. If single braced hangers are used the center of the shaft is to one side and all holes must be laid off that way. Drive a nail with a sharp point through each of the center marks on the board, the middle one a little further than the two end ones; place middle point to center of the shaft line on the ceiling and scribe a cross mark on the line in right angle with the shaft line which was made for each hanger, these marks indicate the location of the holes for the bolts or lag screws by which the hanger is fastened to the ceiling. After all holes are bored and all hangers placed in position in such a way that the bolts are in center of the slotted holes, you may proceed to screw them up tight. Next place your shaft, adjust bearing center and get the shaft in level, it must not be coupled together until finished. When the shaft is in level, stretch a fine silk line (a good fine fishing line will do) equal distance from the two ends of the shaft, parallel to the latter as tight as possible and measure distance from the line to shaft at each hanger, by means of a feeler, which can be made out of wood by cutting out a V-shaped piece at one end and drive a pin or thin nail into the other. By placing the V-shaped end against the shaft the end of the nail must just touch the line.

After the shaft is in line this way, go over with the level again and assure yourself that it has not changed; if it is in line all ends of each section should meet exactly and the ends may be coupled together, all lock-nuts tightened and the shaft is ready to receive the pulleys.

To Hang Countershafts.

To hang a countershaft the proceeding is the same, a line being stretched parallel to line shaft the distance where countershaft is to be hung, and the countershaft is placed parallel with this line. However, if the shaft is very short and the distance from the lineshaft great, the countershaft may be placed as near perfect as possible; a line stretched in right angle extending over lineshaft and countershaft, clamp a piece of wood on the lineshaft with a nail, point outward, driven in. Turn the shaft 180° and see that the point of the nail just touches the line on each side; having placed the line in right angles with the lineshaft, place this piece of wood on the countershaft and adjust it to line and both shafts will be exactly parallel.

Approximate Centers of Bearings for Lineshafting.

Diameter of Shaft.	Centers.	Diameter of Shaft.	Centers.
1 inch........	5 feet.	3 inch........	10 feet.
$1\frac{1}{2}$ inch........	6 feet, 3 in.	$3\frac{1}{2}$ inch........	11 feet.
2 inch........	8 feet.	4 inch........	12 feet.
$2\frac{1}{2}$ inch........	9 feet.		

Shafting is always turned 1/16 smaller than its nominal size. Hangers should never be too light for line shafting to withstand the strain of the belt. It has been found that the most economical speed of shafting for machine shops is from 120 to 150 revolutions per minute, and for wood-working machinery from 200 to 300 revolutions. Do not try to economize in the first cost by placing the hangers too far apart, which means bent shafting and trouble afterwards; protect all set screws or use collars with countersunk set screws. Never place two pulleys in such a position that belt, if accidentally slipping, will clamp between; this will break off a hanger, bend the shaft or tear the belt.

[THE END.]

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ELECTRICAL PART.